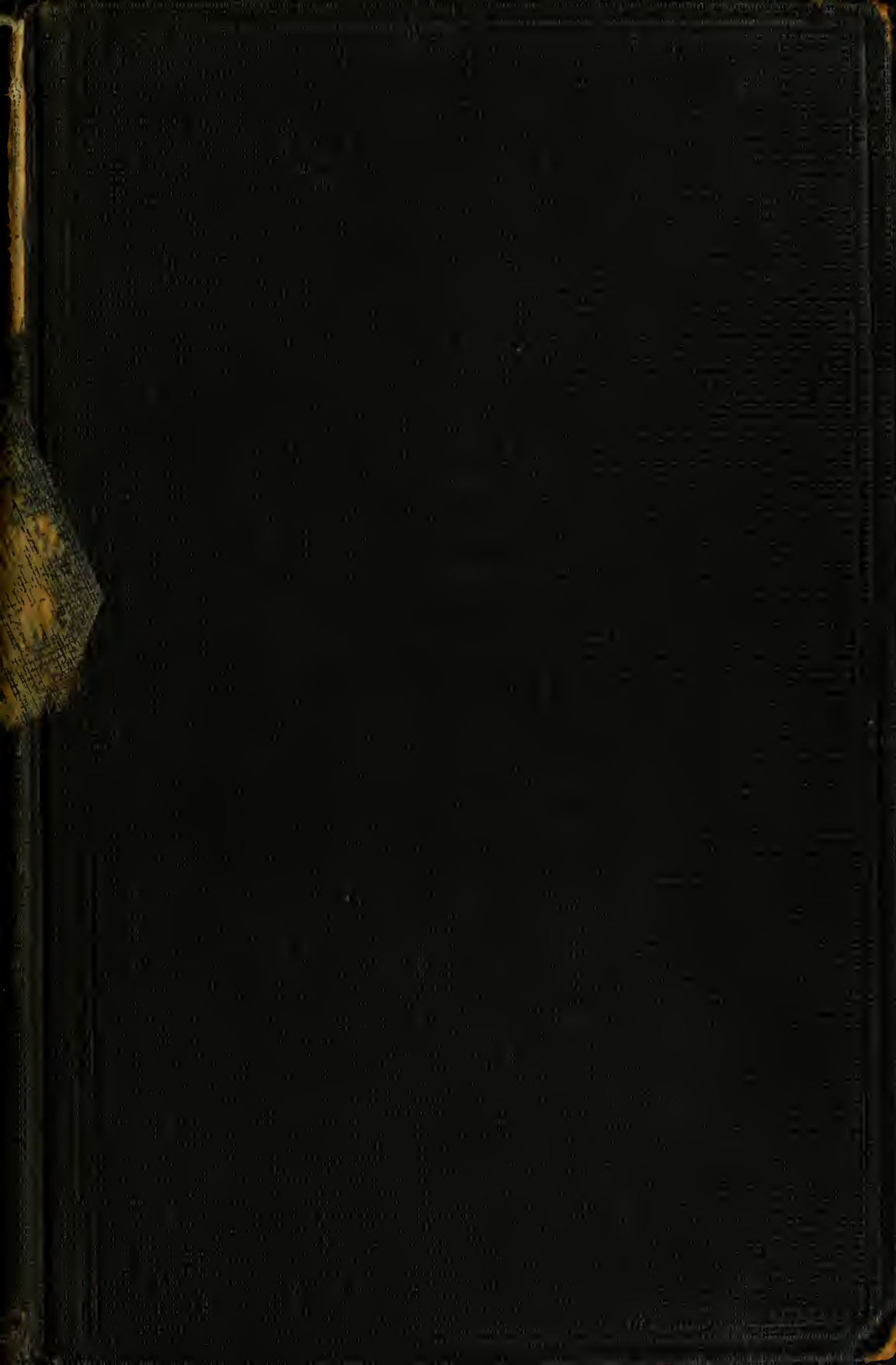


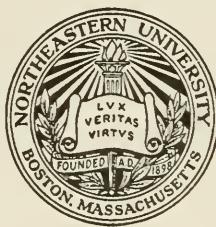


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CITY PAVEMENTS

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(Frontispiece.)

Photograph by the Army Air Service from an altitude of 15,000 ft., showing development of Washington in accordance with L'Enfant's plan.

CITY PAVEMENTS

BY
F. S. BESSON

MAJOR, CORPS OF ENGINEERS, UNITED STATES ARMY
ASSISTANT ENGINEER COMMISSIONER, DISTRICT OF COLUMBIA

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MASON M. PATRICK

MAJOR GENERAL, CHIEF OF AIR SERVICE, U. S. A.

As a token of esteem and in appreciation of his interest
and encouragement which have made possible this book.

PREFACE

The subject matter presented herein has been gathered together during the past four years. My original intention was not the publication of a book, but personal study of highway engineering and the collection of such information as would find practical application in handling highway work in a modern city. In the results obtained I owe much to various officials of the District of Columbia, and especially to two, Joseph W. Dare and Vernon Cleaver.

The publication of my material is undertaken in the hope that others, finding this matter arranged conveniently in book form will be saved many laborious hours, not only in connection with details, but with the larger aspects of the problem of providing satisfactorily for the traffic of a city.

F. S. BESSON.

WASHINGTON, D. C.

May, 1923.

CONTENTS

	PAGE
DEDICATION.	vii
PREFACE	ix

PART I

ADMINISTRATION AND MANAGEMENT

CHAPTER		
I. ORGANIZATION		3
II. PERMANENT PLANS AND RECORDS.		11
III. WORK BY CONTRACT.		21

PART II

PLANNING AND DESIGN

IV. THE STREET SYSTEM.	33
V. THE PROBLEM OF SELECTION	52
VI. DETAILED STREET DESIGN	97

PART III

CONCRETE

VII. CEMENT	139
VIII. AGGREGATES	161
IX. TESTS OF CONCRETE.	171
X. DESIGN OF CONCRETE MIXTURES	181
XI. MIXERS AND MIXING	219
XII. METHODS OF MIXING AND DELIVERING.	231
XIII. CONCRETE CONSTRUCTION	244

PART IV

BITUMINOUS PAVING

XIV. BITUMINOUS MATERIALS AND TESTS.	267
XV. SPECIFICATIONS AND METHODS	307
XVI. DESIGN OF BITUMINOUS MIXTURES.	319
XVII. PLANT AND CONSTRUCTION.	339

PART V

BLOCK SURFACES, STONE CURBS, TREES

XVIII. GENERAL DATA FOR BLOCK SURFACES	357
XIX. STONE BLOCK AND CURB.	369
XX. PAVING BRICK	378
XXI. WOOD BLOCK.	390
XXII. ASPHALT BLOCK.	402
XXIII. TREES FOR CITY PLANTING.	404
INDEX	415

PART I
ADMINISTRATION AND MANAGEMENT

CITY PAVEMENTS

CHAPTER I

ORGANIZATION

1. Bureau of Highways.—There are certain fundamentals of organization that are of importance to all municipal officials responsible for the design, construction and maintenance of city streets. They are also of interest to every private citizen in his capacity both as a city dweller and as a taxpayer. City pavements cost more than any other work of construction carried out by a municipality, but, in many cases, the work is undertaken with no proper organization for its performance.

In a village or small town it is evidently possible that an engineer, in addition to pavement construction and maintenance, might personally supervise all such matters as water supply and sewers, bridges, lighting, street cleaning, snow removal, the collection and disposal of garbage, ashes, and rubbish. As the municipality grows, the details of these several tasks become too great for any one man to handle them, and it is imperative that there should be created a Department of Public Works with separate bureaus thereunder, one being that of Highways, including all work connected with the laying out, construction and maintenance of streets and alleys.

In many cities this same bureau is charged with street cleaning and the collection and disposal of refuse, work which is of major importance, but is entirely dissimilar to that pertaining to the construction and maintenance of the city pavements. The combination in one bureau of two unrelated and independent activities means that the engineer in charge must have under him two division heads, one in charge of paving work, the other in charge of street cleaning and the removal of refuse. Experience is believed to have shown that it is a much better plan to have a Bureau of Highways charged solely with the construction and maintenance of pavements, and a Bureau of Refuse (including street cleaning and the collection and disposal of all refuse), the head of each reporting to the Director of Public Works.

The precise organization of a Bureau of Highways depends largely upon local conditions. However, the principal work to be done by such a bureau is, in all cases, so similar that it is possible to outline in general terms the form which this organization should take. The work of the bureau is divided into two distinct, principal classes:

- (a) Construction.
- (b) Maintenance.

There may also be several minor classes of work.

There are certain municipal activities or functions which, while they concern the Bureau of Highways largely, yet should be handled by separate agencies. Such are those pertaining to filing and mailing, blue-printing and duplicating, purchasing, the accomplishment of contracts, auditing and accounting, motor transport and mechanical shops. Other bureaus, such as Water Supply, Sewers, and the like are equally interested in the proper performance of the functions just outlined, but there will be a saving in over-head and a gain in efficiency if, as suggested, these matters are all handled by central bureaus.

2. Forms of Organization.—Having sketched the duties of the Bureau of Highways, an organization for carrying on the work may be considered. There are two forms of organization, centralized and decentralized, and what may be classed a third, being a combination of the two.

The centralized form is common in business life, as for example, a corporation may have purchasing, manufacturing, selling and other departments. Agencies of each of these may be established in various territories, working independently of each other, and reporting directly to departmental heads in a central office. In this case specialists are developed. Central-office authority is at a distance and action is slow. This authority may not be well informed as to local conditions and one service may work at the expense of another. These points may, however, be of minor consideration since the nature of the business demands, above all, expertness and uniformity of method in each separate activity.

A contractor engaged in a particular line of construction throughout a large part of the country generally adopts the decentralized form of organization. Each separate territory is in charge of a man with full local responsibility who has to act on his own initiative and make quick decisions. Work has to be

adapted to local conditions. In this form of organization, all-round men are developed. Jobs in neighboring territories enter into competition and pride is taken in having the best unit in the organization. All these points are of first consideration. Uniformity of operations among the several territories is of secondary importance.

A military organization is the outstanding example of a combination of the centralized and decentralized forms: The former to insure expertness, the latter to insure direct command

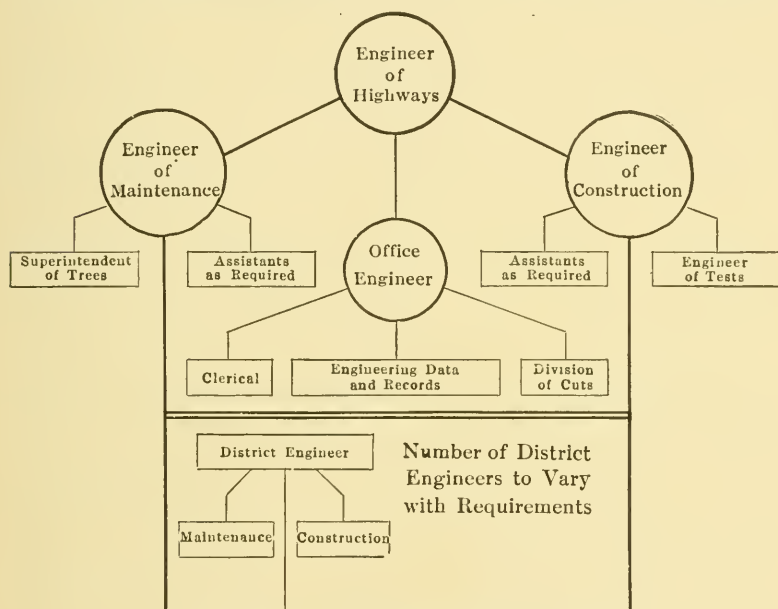


FIG. 1.—Bureau of Highways organization chart.

and speed. In time of peace the tendency is more toward the centralized and in time of war toward the decentralized. Coordination of the two is at all times necessary. Specialists in the various services (supply, medical, air, engineer, etc.) must not interfere in local operations without the knowledge of the unit commander.

3. Organization of the Bureau of Highways.—The larger a city the greater the necessity of following the military organization. State highway departments have found the system particularly adapted to their needs. Figure 1 is an organization chart that in general meets the requirements of a city. The Engineer of

Highways has two principal expert advisors, the Engineers of Construction and of Maintenance. The work in the separate territories is in charge of local men called District Engineers, each district being in reality just like a small city.

It is a question when, as a city grows, division into districts should be made. No two cities are alike. Many different physical, financial and other conditions must be considered, and again, much depends upon the personal qualities of the engineer in charge. Generally, in a fairly prosperous and progressive city of 20,000 inhabitants, paving work alone is of such importance that the appointment of an Engineer of Highways is well justified. As the city grows his organization should conform to the general rules already set forth. In expanding, the first step is the employment of a District Engineer, and next, the formation of additional districts. Feeling the need of assistance in correlating the work of the District Engineers, the appointment of either an Engineer of Construction or of Maintenance is made, for instance the latter, while the Engineer of Highways personally directs construction work. Finally, an Engineer of Construction is also employed.

4. Construction and Maintenance.—One essential and practically universal difference between the work of construction and that of maintenance is that the former is habitually done by contract, the latter by day labor. The relative importance of these two classes of work depends upon circumstances and, as these vary, one or the other class may be the more important. Maintenance must proceed uniformly, season by season, whereas construction may fluctuate periodically, depending upon the growth of the city and the relative urgency of the many demands upon the city's budget. Thus the routine work of a district is maintenance which is carried out by a regular force of superintendents, foremen, and laborers. When surveying, resurfacing, or construction is contemplated, the District Engineer needs the help of one or more field parties with assistant engineers, transitmen, inspectors, etc. and such personnel is ordered to report to him by the Engineer of Construction.

5. The Superintendent of Trees.—Under the Engineer of Maintenance in Fig. 1 is shown a Superintendent of Trees whose position requires some explanation. Notwithstanding the fact that people readily recognize the value of trees, only rarely is there a capable official charged with their propagation, transplanting

and care. By the individual efforts of property holders a scattering arrangement of poorly selected trees may be possible; but, in order to have a really worth while tree system, full municipal control is necessary. The Bureau of Highways is the proper agency of the city government to take charge of tree planting and maintenance.

Plantings are usually not authorized for streets until both sidewalk and curb are in place. Tree work on the street then consists in digging holes, filling them with rich soil, planting, cultivating the earth around young specimens, protection of trees, trimming them, and insect extermination; all of which work naturally falls under the jurisdiction of the Engineer of Maintenance. However, if the tree system is at all large, he needs the assistance of a Superintendent of Trees, particularly so in view of the fact that the city should grow its own seedlings in a municipal nursery.

6. The Office Engineer.—Directly responsible to the Engineer of Highways there must be an executive or business manager who may be called the Office Engineer. His office force consists of clerks, computers, and draftsmen, and his office relieves the Engineer of Highways of many tedious details. Requisitions, payrolls, the certification of bills payable, statements of allotment balances and other records affecting the finances of the bureau are handled in this office. Here, too, all engineering records are likewise concentrated.

Having all data at once at hand, the Office Engineer is the proper person to deal with citizens applying for information as to prospective or desired improvements. Such business with the public requires much tact and ability, and a great deal of time is thus consumed. Not a building is constructed but information has to be obtained of the Bureau of Highways as to grades, sidewalks and terraces, and in many instances, as to curb and roadway improvements. Permits have to be obtained and deposits made in order to guarantee that public improvements such as sidewalks and trees will not be injured during the construction of buildings.

A most important duty of the Office Engineer is the control of work done in public space; as driveways across sidewalks and curbs, street openings by plumbers and utility cuts; together with the keeping of records and accounts connected therewith. This work is of such importance that a separate division is necessary

under the Office Engineer, the duties of which may be discussed under a separate heading.

7. Division of Cuts.—As the demands for modern conveniences of life multiply, it daily becomes more urgent to regulate properly many constructions beneath the surfaces of city streets. Control is necessary for the regulation not only of the location of mains, conduits, and other sub-structures, but also of the cutting of pavements in order to install them. Provision must, of course, be made for water, sewer and gas pipes, and it is now not unusual to have to provide for telephone and lighting cables, for tunnels for industrial and commercial purposes, and in the larger cities, for underground railways.

Before outlining in detail the work of the Division of Cuts, it is well to set forth briefly the larger aspects of the problem. Some sub-surface constructions, those of greater consequence, require special consideration by the City Government. Installations in accord with settled municipal policies should be under the control of the Director of Public Works, who should appoint a permanent Supervisory Board consisting of the bureau engineers in charge of water, sewers, lighting and highways. Maps drawn to a single scale should be available from each bureau represented on this board. On a set of maps from each bureau are shown the sub-structure data pertaining to it. In addition it will be necessary for the board to have prepared a set of maps showing all data not plotted by the several bureaus.

A successful Supervisory Board is of lasting benefit to the municipality. First, by its allocation of sub-surface space, it conserves one of the greatest assets of the city, and incidentally, through making an accurate and complete historical record available, it facilitates the actual construction of improvements. Secondly, the Board regulates underground work by coordinating the grading work of the Bureau of Highways with desirable extensions of water mains and sewers and the like that should be made by the municipal bureaus or by private corporations. When new paving is contemplated, consideration is given to future as well as to present sub-surface requirements, and such work as is possible is done so as to obviate tearing up new pavement for a reasonable time. When the construction of longitudinal extensions or of new systems under existing pavements is desired, the Board gives consideration to the necessity therefore, and to the probable damage to existing surface improvements. In some

eases it may be advisable to order owners of vacant lots to install lateral house connections prior to the construction of a pavement. Some cities have a fixed rule that new pavements shall not be cut for 2 or 3 years after being laid. It is believed to be better practice to depend upon the judgment of a Supervisory Board as has been outlined.

All cuts in pavements are made under authority granted by permits. If the permit is asked for a longitudinal cut, the matter must be referred to the Supervisory Board prior to issuance. If a permit is wanted for a service connection, or other small job, it issues automatically. In any case the Division of Cuts has prior knowledge of all impending work. This is primarily essential. It is likewise imperative that there be supervision of the restoration of surface conditions.

This restoration of surface conditions, or repair of cuts should habitually be made by the District Engineers supervised by the Engineer of Maintenance. In exceptional cases it may be proper to permit such work to be done by a private corporation, but in such cases the work should be supervised by a city inspector, and his salary charged to the corporation, which should also bear a proportionate share of the over-head expense of the Divisions of Cuts. Experience has shown it to be doubtful whether any economy ever results from permitting private enterprise to do such work. Public interests are best served by the city doing the work itself.

The Division of Cuts must be self-supporting, though a profit should not be made. In general, a special working fund is established by deposits made by public service corporations, plumbers and others finding it necessary to open up pavements. If a repair to a cut made by a municipal bureau is necessary, the fund is reimbursed by a transfer voucher. In some instances, instead of a deposit, corporations have been permitted to furnish a bond. Especially is this the case when the private concern is allowed to make the repair and the bond then serves as a guarantee of good work. Experience has shown the excellency of the deposit system. The amount maintained by a corporation may vary with conditions, and by a plumber \$50 appears to be a fair average sum. Bills should be rendered monthly, charges made against deposits, and, in each case, no permit for further work issued until, through payment of the bill, the deposit has been returned to its normal amount. With a satisfactory administrative procedure

for the control of cuts it is an easy matter to arrange for their repair under the superintendence of the Engineer of Maintenance.

Information as to work in the field is furnished by means of a card system, which can be readily devised to meet local conditions. Upon the issuance of a permit granting authority to make a cut, cards in duplicate containing all necessary information are prepared. One copy is retained and the other given the District Engineer supervising work in the locality. Through his organization and knowledge of plumbers and others working in his district, it is an easy matter to prevent abuse of pavements in the making of cuts and to obtain good work when these private parties back-fill their trenches. Surface repair is made by the District Engineer when conditions as to the type of pavement and back-fill justify complete restoration.

Upon return of cards to the Division of Cuts with measurement and other data from the districts, proper charges against deposits are made. It is usual practice to base these charges either on actual cost plus a percentage for over-head or on flat rates. The former method serves well for unusually large jobs but ordinarily a flat rate, that is, a listed charge per square yard for each type of pavement, is fair, convenient and justifiable.

CHAPTER II

PERMANENT PLANS AND RECORDS

8. The Necessity of Plans and Records.—Maintained under the direction of the Office Engineer are the usual records of engineering and construction: Field-book files, books of estimates, time keepers' and foremen's field sheets, labor and material cost records, and other information with the preservation and use of which engineers are in general familiar. In addition, there are certain maps, plans and other data, the absence of which in the files of many towns and cities warrants their being discussed at length, not from the standpoint of the details of design but rather from the viewpoint of administration and management.

While specific methods of originating and preserving records of highway improvements are stipulated, they may be modified to meet various conditions. The main purpose is to lay emphasis on the necessity of work of this character and to outline the many requirements. The cost entailed in the preparation and maintenance of such maps and records as are utilized has been proven justified by the experience of many important cities. The cost in minor cities, no matter how small they be, will be found to be money well spent.

9. Topographic Map.—It is of vital importance to have a topographic map accurately prepared to suitable horizontal scale and vertical interval. Such a map facilitates work in practically all branches of municipal engineering and its cost is well justified by the efficiency and economy it promotes. For many localities it is possible to get U. S. Geological sheets drawn to a 1:62,500 scale with 20-ft. vertical intervals. For certain restricted areas maps are available to a 1:31,680 scale with 10-ft. vertical intervals. While these maps are helpful, they are not entirely satisfactory for municipal purposes. A larger scale map is better; one prepared with accuracy to a minimum horizontal scale of 1 in. to 400 ft. with 5-ft. vertical intervals will be found very useful in highway engineering.

10. Highway Plan.—Of next importance is a permanent highway plan covering the entire area of the city, for without it a

rational development is impossible. There must be enough major traffic and transit streets and, at the same time, a proper net work of minor ones. All condemnations or dedications must conform to this permanent plan. Once prepared, changes in this plan should be avoided and none should be made without consideration by the highest municipal officials. In this manner the best interests of the community are furthered. While in some instances it may be advisable to provide straight alignments and minimum grades, even though heavy grading be necessary, as a rule the highway plan should be made to conform to the terrain. Unless such a permanent highway plan is adopted and followed, it will be found that expansion of the highway system is controlled by the whims of land speculators; property lines will determine street locations, sub-division of land into lots will be unduly favored, and a hodge-podge system of highways will be the result (see also, Chap. IV).

11. Street Grade Sheets.—With a topographic map and a highway plan the preparation of a set of drawings on sheets about 40 by 24 in. showing center-line profiles and grades is simple. Work on these Street Grade Sheets, a satisfactory scale for which is 1 in. horizontal = 200 ft. and 1 in. vertical = 20 ft., is under the supervision of the Engineer of Construction and is of a more or less continuous nature. It should at all times be in advance of the growth of the city. The data on these sheets are a great aid in the satisfactory extension of water, sewer and gas services. As localities develop and surveys are made, it may be found that minor corrections and grade revisions are necessary. When abutting property has stabilized and conformed to approved grades, changes should be made only after grave consideration.

On each sheet, in tabular form, are shown the dates of original grade lines and revisions. The initials of the District Engineer will indicate that he is satisfied with the lines and grades; of the Engineer of Construction that he recommends approval; of the Engineer of Highways that he gives final approval. In addition, in order to record the concurrence of that official, the initials of the head of the bureau having charge of sewers likewise appear.

Drainage and the accommodation of traffic are the two foremost considerations in grade control, but sometimes, and usually to the detriment of drainage, other items such as the cost of cut and fill and the effect upon abutting lands, are given undue weight. The system outlined safeguards all interests.

12. Street Work Sheets (see Fig. 2).—In connection with the improvement of newly developed portions of the city and the betterment of conditions in the older areas it is necessary to record a mass of detail grade data. These data are worked out and platted by the District Engineers and filed by the Office Engineer. In order to facilitate ready reference, the drawings are of a uniform size on paper of sufficient weight to stand much handling. A cap-size sheet, 14 by 17 in., using standard cases, is convenient

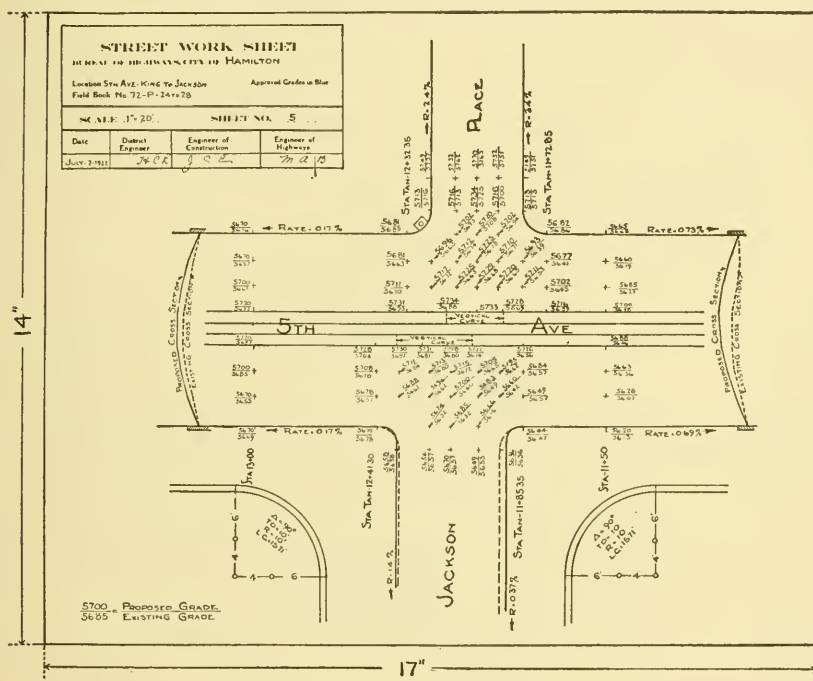


FIG. 2.—Street work sheet.

for filing, and, on a scale of 1 in. = 20 ft. permits a stretch 320 ft. in length to be shown. For longer work either the entire length need not be shown on a single sheet or the scale may be reduced. Various colored inks may be used to advantage in order to show different information. It is from these work sheets that property owners obtain curb and sidewalk grades when they desire to build. If, in reconstruction of sidewalks, much adjustment of grade is contemplated, it is necessary to plat data pertaining to abutting private property in order that old established conditions

may be given proper consideration. For construction purposes a cut and fill table, together with other desirable information, is attached to the Street-work Sheet and made part of the permanent file. When necessary, additional papers are attached showing details drawn to larger scale. The sheets are dated, initialed by the District Engineer, the Engineer of Construction, and the Engineer of Highways.

13. Alley Sheets (see Fig. 3).—Plans are necessary for alleys similar to those for streets with the exception that grade and work

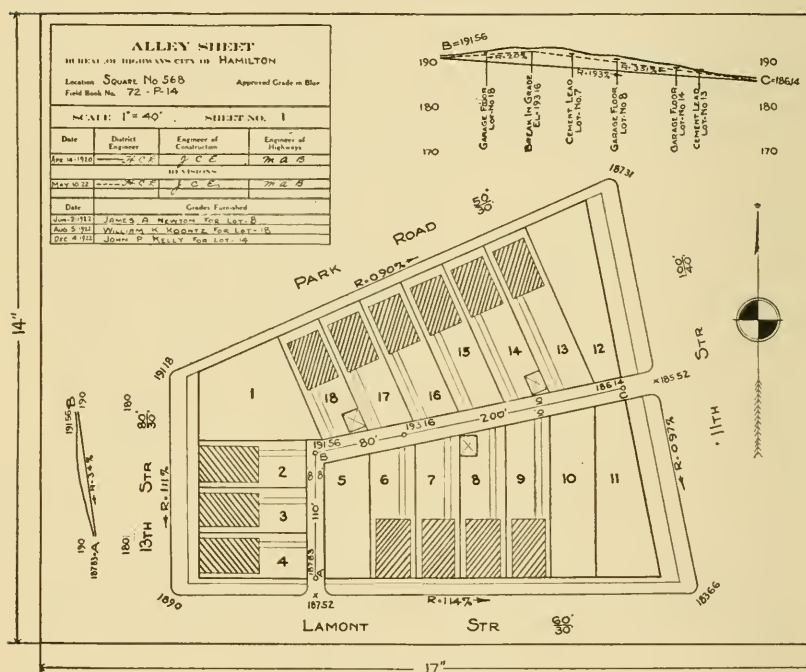


FIG. 3.—Alley sheet.

sheets are combined as Alley Sheets. Since alleys are not wide and are usually given a dished cross-section, with no curbs, a center grade line shows most of the data required. Some information relative to the streets surrounding the square in which an alley is located, particularly at the alley entrances, is also necessary. When construction is to be carried out, a cut and fill page is attached to the Alley Sheet, and the elevations of garage floors and leads to private property are indicated. The sheets are

dated, initialed by the District Engineer, the Engineer of Construction and the Engineer of Highways. As property improves, alley grades prior to permanent paving are subject to many minor changes. Each revision is recorded on the sheet and properly authenticated. Care has to be exercised not to cause damage to property owners within a square through alley-grade changes, therefore, each sheet contains a record of owners that have been furnished grades in order that they may be properly taken into consideration when a revision is contemplated.

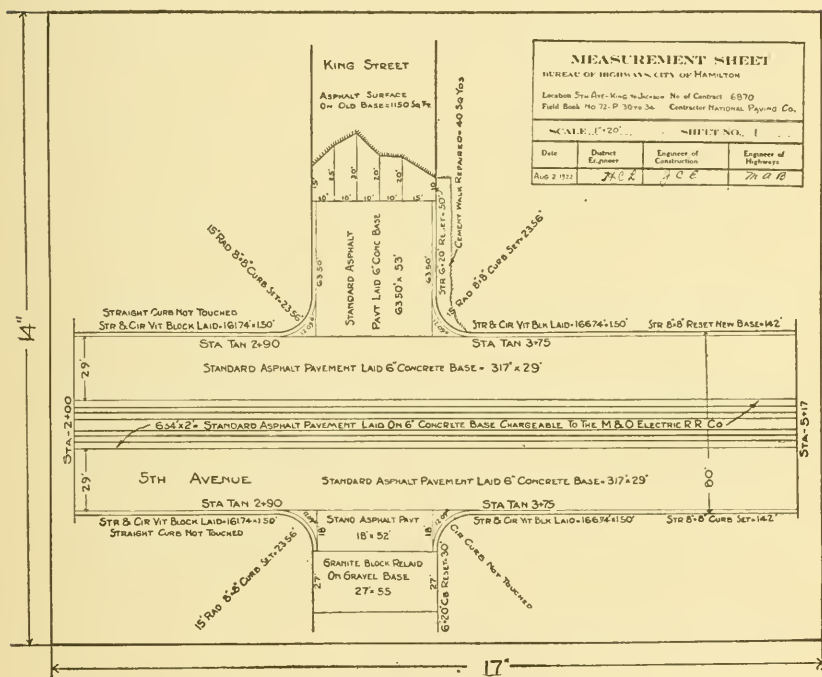


FIG. 4.—Measurement sheet.

14. Measurement Sheets (see Fig. 4).—Measurement Sheets are prepared upon the completion of all construction, whether roadway, sidewalk or alley paving. These sheets are an aid in drawing up the final statement upon which payment is made on a contract. Colored inks can be used to bring out different phases of the work. Extra sheets are used in order to show to a large scale such details as may be necessary. A recapitulation in tabular form of all the items making up the final statement is attached to the measurement sheet.

15. Highway Maps.—Information as given on Measurement Sheets are platted on Highway Maps drawn to a 1 in. = 50-ft. scale. A satisfactory size for these maps is 24 by 32 in. In this manner is kept in permanent form an accurate record of highway improvements, a record that is at all times up to date and available for ready reference. Different pavement surfaces are indicated by written descriptions, curbing of various kinds by different colors and weights of lines, symbols are used for details such as different types of catch basins. Various species of trees and much other data are shown by the use of convenient conventional signs. By a judicious choice of the matter to be shown on these maps, everything essential to the daily routine work of the Bureau of Highways is indicated without undue crowding. Using a 1 in. = 50-ft. scale, even a small detail, for instance a 6-ft. radius circular curb, may be drawn accurately to scale.

16. Progress Maps.—Three maps of the city are maintained by the Office Engineer showing highway improvements to date and the status of current work. One map for roadways, one for sidewalks, and the third for alleys. A scale of 1 in. = 1,000 ft. is about the practicable minimum for this purpose. Colors are used in order to indicate different types of paving. For inferior pavements such as are usually at a latter date replaced by better surfaces, light colors are used in order that other colors may be placed over them for the purpose of indicating the higher types. For instance, macadam and cobble roadways and brick sidewalks are represented by light colors; asphalt and concrete roadways and cement sidewalks by dark colors. In order to show the location and character of work in progress, flags made of different colored bits of paper containing brief written descriptions are fastened to pins and stuck on the maps.

Similar maps are made use of by the Engineer of Construction and Maintenance, their assistants, and the District Engineers. For these, since the work to be shown is not of great amount, it can be shown in detail, particularly so in the case of the District Engineers because, for their limited areas, large-scale maps can be utilized.

17. Cost Keeping.—The U. S. Department of Agriculture *Bulletin 660* issued by the office of Public Roads contains much valuable information on Highway Cost Keeping. This pamphlet may be obtained from the Superintendent of Documents, Washington, D. C., at 10 cts. a copy.

The points to be considered in cost keeping are Labor, Materials, Plant and Equipment, General Expenses and Contractor's profit. Data are useful not only to show current costs for administrative purposes, but also to point the way to more efficient and economical work. However, conditions on no two jobs are identical and on any one job they vary from time to time. Therefore, considerable knowledge and understanding of local conditions are needed before future costs can be forecasted with sufficient accuracy to insure full success in drawing up estimates.

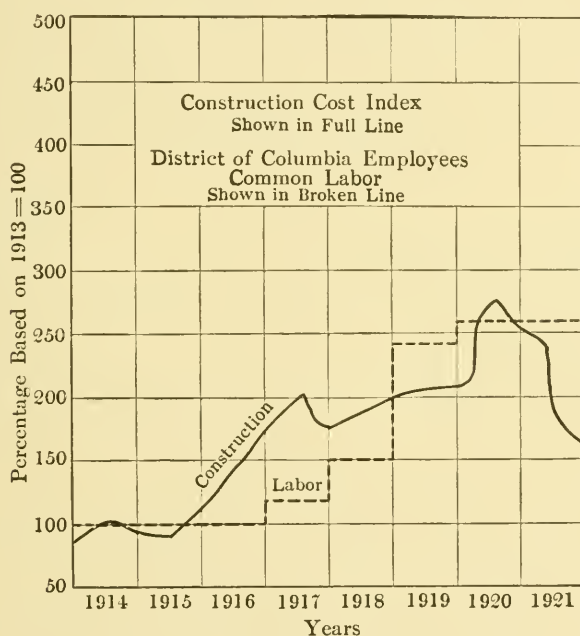


FIG. 5.—Chart showing construction cost and common labor indexes.

Interest in construction statistics has developed greatly in recent years and several engineering periodicals regularly publish very useful data. In Fig. 5 the solid line shows the *Engineering News-Records'* Construction Cost Index based on the year 1913 as 100. In computing the index numbers, steel, cement, lumber, and common labor are taken as the fundamental elements in construction. As their prices change, construction cost will vary the country over. Weights are assigned to the assumed relative importance of the several items: Steel, 37.50 per cent;

cement, 7.14 per cent; lumber 17.10 per cent; labor, 38 per cent. While this graph is of national value, local data may be plotted in a similar manner and engineers should do so, for the items entering into their own work. For instance, the broken line in the figure represents common labor conditions in Washington, D. C. and the trend of material prices will be shown in later chapters dealing with the particulars of construction.

In making up costs, plant and equipment charges are the most difficult to fix. Machines depreciate not only while on the job but also while in storage. Timely repairs or the lack of them make a great difference in the length of service secured. There are several ways in which plant and equipment charges may be made. The simplest and most practicable is to charge a rental, either per day or per unit of work. For example, in the case of a concrete mixer with a life of 5 years:

	PER CENT OF ORIGINAL COST
Depreciation in 5 years.....	100
Repairs at 12 per cent per year.....	60
Interest, storage, insurance at 8 per cent per year...	40
Total charges for 5 years.....	200
Daily rental at 100 days work per year.....	0.4
Rental per 1,000 cu. yd. at 100 cu. yd. per day.....	4

Charges for fuel and other supplies are definitely ascertainable and need not be included in the rental charges.

Every item of plant and equipment held by an organization should be studied and tabulated as illustrated in the preceding paragraph. If through good management a machine is maintained serviceable beyond its expected life the charges should continue as a matter of administration in order to insure fully comparable cost data on all jobs.

General expenses should be separated into those directly connected with the job, as expenses for inspection, field parties, tests, etc., and those connected with general administration, research and other items that cannot be wholly charged to any one particular project. Care should be exercised not to include in general expenses a number of miscellaneous and contingent charges that rightly should be itemized and form part of the unit costs, just as labor and material do. In making up estimates it is necessary to carry a lump sum for unforeseen and chance items;

but in reporting on current work everything should be itemized as far as practicable.

While an average of 15 per cent is considered a contractor's fair profit, the amount should vary with the character of the work. If it is mostly a matter of furnishing materials, the profit need not be as large as when there is a great deal of labor and transportation involved or when there are many unforeseen contingencies that may arise.

18. Record Cards.—Periodically, for all roadway pavements, information should be taken from current cost data and posted to 3 by 5-in. record cards, one card for each block length of pavement. These cards are not as necessary for sidewalks and alleys which do not present such a complex situation as do roadways. On one side of a card is recorded the construction cost of a pavement, on the other side maintenance year by year. In every city there is a substantial yardage of so-called out-of-date roadway pavements, and always more or less continuous agitation for its replacement with expensive construction. The record cards provide a good basis for judgment as to the economy of such desired replacements. Cost data as kept on these 3 by 5-in. cards are essential in order that a fair comparison may be made of the worth of different types of surfaces used in a city.

19. Traffic Records.—Traffic makes roadway pavements worth while and traffic wears them out. Its amount and its characteristics are important. Traffic data alone, however, are of slight value—they must be tied together with cost data. A traffic census taken today cannot show what the traffic will be in the future. In order to plan successfully for the future, the Engineer of Highways must know his city, its terrain, its commercial and industrial centers, and its residential areas. This is a matter which is taken up in Chap. IV and discussed in its relation to Zoning and the development of a Highway Plan.

It would be well if a traffic census could determine the relative cost of service rendered by various pavements per ton of traffic carried. All traffic records should be kept with this end in view which matter is dealt with in Chap. V, "The Problem of Selection," but unfortunately to date we have available practically no dependable data showing the wear due to traffic on pavements of various types constructed under various climatic and sub-soil conditions; and even fewer data as to the cost of operating traffic over pavements of various types and conditions. Obtain-

ing the total numbers of each class of vehicle and the total tonnage using each street under investigation, is only the first step. It is then necessary to study maintenance costs, transportation costs, and the many elements that affect both. Until the entire problem is solved and all the facts are known true economy of highway building and highway transportation is of doubtful attainment.

CHAPTER III

WORK BY CONTRACT

20. Classes of Contracts.—Construction is commonly carried on under one of two forms of contract—the cost plus and bid price. The cost-plus system on a percentage basis where the higher the cost the greater is the contractor's profit is in bad repute because unscrupulous contractors may unduly increase the cost. The cost plus a fixed fee is not so objectionable since there is not present the incentive for the contractor to disregard or enhance the cost. Under this form moderate cost, excellent workmanship and compliance with the specifications are necessary if a contractor is to continue in business. In public work, however, an official has little or no discretionary power in selecting a contractor as he must generally use the bid-price form of contract after first advertising for bids. Under this form the cost of the work is known in advance.

21. Contractual Relations.—There is need of standardization in paving specifications, not only as to materials and workmanship but also as to relations between contractors and owners, the latter being the public as represented by its officials. The engineer obtains best results only by reducing the contractor's risk to a minimum. Specifications should be so drawn that under fair competition the most competent man, and not the most irresponsible, will be the successful bidder. Unnecessary or unreasonable stipulations in specifications must be avoided. Otherwise, reputable contractors will refrain from bidding with the result that bids will be received from only irresponsible contractors, and, in the end, the cost to the public will be greatly increased.

An engineer should have clearly and definitely in mind the work he desires accomplished. He must be sure that his specifications describe just what is wanted. Lack of definite knowledge as to what is required is no excuse for such unreasonable terms as "the work shall be done to the satisfaction of the engineer." Specifications that are satisfactory both to the

engineer and to the contractor result not only in a profit to the contractor but in a lower cost to the public.

22. Fall and Winter Letting of Contracts.—It generally takes a contractor a month or two to organize and get ready to begin pavement construction and about as long a time to reach his maximum output after he starts construction. For this reason

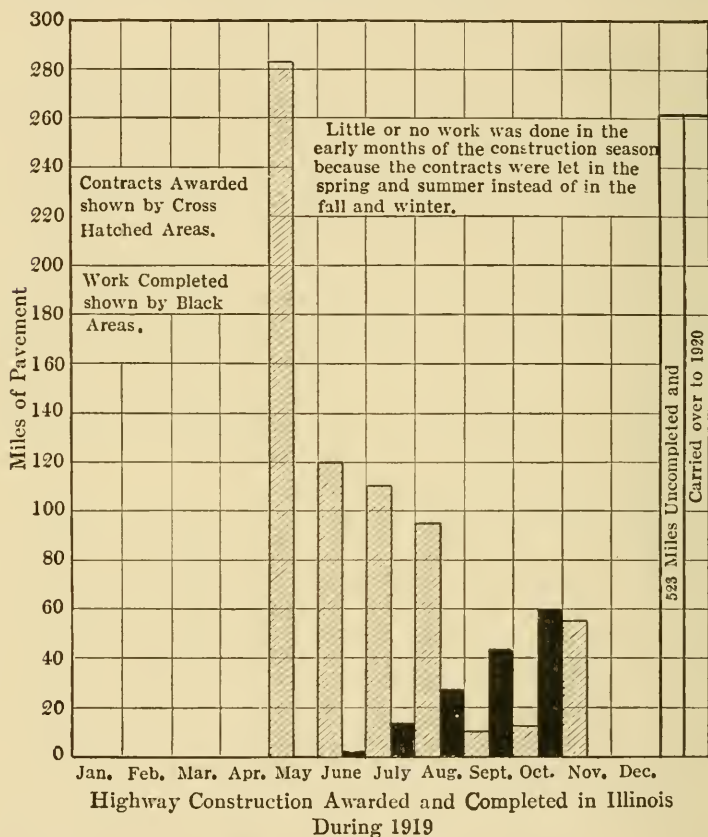


FIG. 6.—Letting contracts in the fall and winter takes full advantage of the open working season, and cuts down the amount of work that has to be carried over to a subsequent season.

contracts should be let during the fall and winter months in order that the maximum benefits may be obtained of the open working season. The further north the more important is this feature, while in the south and other places of small climatic variations it is not so important. Even where there is an all year construction

season it is well to realize that it takes a contractor several months to get fully under way and, accordingly, work should be prudently advertised at as early a date as practicable and the contractor given the benefit of all available time. The data for the chart shown in Fig. 6 were prepared in Illinois, in order to set forth the main advantages of fall and winter letting of contracts. If the contractors had been able to start work at the beginning of the open season, not only would the actual available time have been lengthened, which is plainly evident from the chart, but the maximum output for the peak month and the average per month would both have been correspondingly increased. One objection has been raised to fall and winter letting. In a declining market more would be paid for labor and materials under such contracts than under those let the following spring. The same objection, however, applies to that work, which under present conditions of spring letting remains unfinished in the fall, and is carried over the winter. Some of the risk connected with contract work could be eliminated if it were practicable to provide for all work carried over, changes in unit prices proportional to the changes in the cost of materials and in prevailing wage rates.

23. Unbalanced Bids.—Unbalanced bids are generally due to faulty specifications which give certain bidders, more familiar than others with the local application of these specifications, an unfair advantage. The result is that while the contract is apparently awarded to the low bidder, the city actually pays more than if award had been otherwise made.

As an example, suppose that bids for sidewalks are requested on two counts. (a) A square-yard bid for a number of large items confined to the main part of the city and (b) a square-yard bid for a large number of small items scattered throughout the suburbs of the city. If the number of square yards under (a) and (b) are equal, for instance 20,000 sq. yd. for each class, an award can be made on an average of the unit prices bid. If one bidder asks for (a) \$2.47 and for (b), \$2.53, his average would be \$2.50; and if another asks \$2.24 and \$2.66 his average would be \$2.45 and this latter would be the low bid by a total of \$2,000. If it turned out, however, that 30,000 sq. yd. of class (b) were actually constructed and 10,000 sq. yd. of class (a), the \$2.47 and \$2.53 bid would be low by a total of \$1,800.

This matter of unbalanced bids is brought up because of its frequent occurrence in actual practice. Where the work is divided

into classes the amount of each class should be definitely stated and must not be varied. Cases often arise in connection with grading and material hauling contracts when the length of haul is increased over that originally contemplated and paid for as over-haul. Because of the difference in prices bid for over-haul, and its common occurrence, the total paid the originally accepted low bidder turns out to be more than would have been paid other bidders if in the first instance the bids had been properly canvassed, or if the specifications had been more carefully drawn.

24. Guarantee and Maintenance.—In many cities contractors are required to guarantee paving for a number of years. This practice is a survival from the early days of patented bituminous mixtures. The contractor was then a guarantor that work in accordance with his design would prove successful. When specifications are prepared by the municipality and the contractor is required to bid thereon, as distinguished from a submission by him of his own plans, he should not be compelled to guarantee the results that the specifications will give. Bids for pavement construction are often required to include maintenance for a term of years. A contractor can do no more than make a guess as to what this maintenance will be. If his guess is too high, he makes an extravagant profit, if too low he will slight his work whenever he can. In either case the city loses, so it is true economy to contract in the first instance for construction only, and to provide for maintenance by the city itself.

25. Inspection.—While supervision is the duty of the engineer, he has, however, to delegate detailed inspection to a representative continuously on the job in the field. It is difficult to get good inspectors. The duties are not hard, but the position is trying. To a man with ability and ambition the close confinement on the work with little to do except keep his eyes open is irksome. A common mistake of inspectors is to interfere with the conduct of the work by giving workmen orders direct. They must deal with the representatives of the contractor, foremen or higher officials. An inspector must understand his specifications, be concisely instructed in his duties, and capable of performing them. He must have an even temper, be considerate yet firm. He must look ahead and prevent misunderstandings that would have to be adjusted by the engineer before the work can progress. The contractor sells service, the public wants results; but only by cooperation can work be obtained to the satisfaction of both.

26. Standard Specifications.—It is seldom that contractors limit themselves to restricted localities. Standardization of specifications throughout the country would be welcomed by contractors as broadening their field of work. Adoption of the standard by a particular community would tend to wider competition in the bidding. Contractors bid freely on well-known and accurately described work but fear the risk when such wording is used as: "The materials shall be of the best quality and mixed in proportions depending upon their character and the traffic upon the street to be paved." The U. S. Bureaus of Standards and of Public Roads have issued standard specifications to a limited extent, and so have certain engineering societies and commercial associations. Federal official publications have a stamp of authority about them and are available to the public without restriction. It is hoped that, in the near future, many more standard specifications drawn by Bureaus of the Federal Government will be available. In the meantime, cities should make full use of those thus far published.

27. The Composition of Specifications.—The subject matter in specifications may be divided into two classes: Matter which varies with each job and that of general application. Those parts differing with each contract are dealt with under the following headings:

- The Cover Page.
- Notice to Contractors.
- Proposal Form.
- Special Provisions and Details.
- Construction Details.

Those portions of specifications of general application are:

- Definition of Terms.
- Instructions to Bidders.
- Award and Execution of Contract.
- General Stipulations.

The requirements under these general headings should be the same for all contracts. They may be printed as one set of papers and be of service not only to the Bureau of Highways, but to all bureaus of the city. Separate sets of "Construction Details" may be printed for each general class of work as "One-course Plain Concrete Pavements," "Sheet Asphalt Surface Course," etc. Papers of general application may be kept in stock in sufficient numbers to serve for several contracts. For any one

contract the ones required are combined with those parts of the specifications requiring separate printing, because describing particular schedules of work to be done. Some cities have gone to extremes in preparing book-form specifications covering all types of construction. It is not only uneconomical to use bulky miscellaneous specifications when but a single job is on hand, but it is confusing to many contractors to search through many items in order to find the few details relating to their respective bids. It is common, also, to find that, in order to save printing a revised volume, book-form specifications are full of crossed out sections and pasted in corrections.

Letterhead is a convenient size for specifications unless the city draws its contracts on a different size. It is well to have both of one size since the specifications and contract are bound together and form one document. In the body of specifications, the various parts are indicated by headings in bold face type. The arrangement should be as outlined in the following paragraphs.

28. Cover Page.—The cover page contains the name of the city and the title of the specifications in bold face type. Also a table of contents or index.

29. Notice to Contractors.—Information as to proposed work is circulated by advertising for proposals and by sending "Notice to Contractors" forms to prospective bidders. The information given is as follows:

- (a) Time and place of receiving and opening proposals.
- (b) Brief description of proposed work.
- (c) Place where plans and specifications may be examined or secured, and from whom information may be obtained.
- (d) Rights reserved to reject any or all proposals.
- (e) Any additional information thought necessary.

30. Proposal Form.—It is most convenient to have the proposal form printed directly beneath the "Notice to Contractors." Bidders like this position on the first pages of the specifications. Also, it is a handy location for the engineer who canvasses the proposals and makes up a schedule of bids. The form should contain:

- (a) Suitable heading and introduction.
- (b) Declaration of the bidder that he understands the specifications.
- (c) Itemized proposal showing schedule of work and approximate quantities with spaces for prices bid.
- (d) Statement as to amount of contract bond.

(e) Bidder's guaranty that he will, if his bid is accepted, enter into contract in the form adopted by the city.

(f) Spaces for signatures, titles, etc.

31. Definition of Terms.—Those terms ordinarily needing interpretation are: "City," "Bureau," "Engineer," "Inspector," "Laboratory," "Bidder," "Contractor," "Surety," "Proposal," "Proposal Guaranty," "Plans," "Specifications," "Contract," "Contract Bond," and "Notice to Proceed."

In addition to explaining the meaning of the terms "Specifications" and "Contract" it should be clearly set forth that all matter contained under the various headings and sub-headings printed in the specifications, together with the contract and all papers or plans attached to either, as well as all supplemental agreements are to be considered one instrument.

32. Instructions to Bidders.

(a) Bidders required to examine the plans, specifications, special stipulations, etc. and also the site of the proposed work.

(b) Bidders' attention called to necessity of being familiar with laws affecting the work.

(c) Instructions for filling in proposal form.

(d) Requirements regarding signatures on proposals.

(e) Prohibition of alteration, erasures, etc. on proposal forms.

(f) Reference to form of guaranty required—certified check, to whom payable; or, proposal bond, how executed. In case a bond is used a guaranty form complying with local legal requirements should be furnished with the proposal form.

(g) Instructions for submitting or delivering proposals.

(h) Statement that proposals may or may not be withdrawn. In case withdrawal is allowed, the bidder should be obliged to file his written request not later than the day previous to the opening of the proposals.

(i) Opening of proposals. Time and place and invitation to bidders to be present.

(j) Disqualification of bidders. No right to submit more than one proposal; collusion, unbalanced proposals; failure to carry out previous contracts; and lack of experience and capital.

(k) Any additional clauses thought necessary.

33. Award and Execution of Contract.

(a) Right reserved to reject any and all proposals and to waive technicalities.

(b) Award of contract. By whom, place, to whom, and when made.

(c) Return of proposal guaranty. How and when returned.

(d) Contract bond required. Reference to form furnished by city and to the amount shown in proposal.

(e) Execution of contract. Time and place. Reference to form furnished by city. The Department of Commerce of the Federal Government has been cooperating with the National Engineering and Contracting bodies in order to standardize the documents used for contracts.

(f) Failure to execute contract.

(g) Restrictions relative to subletting or assigning contracts.

34. General Stipulations.

(a) Scope of work. General statement relative to performing work and furnishing tools, labor, equipment, etc., and performing work in accordance with the plans, specifications, and contract.

(b) Duties of Engineer, Assistants, and Inspectors.

(c) Interpretation of specifications and plans.

(d) Lines, grades, measurements.

(e) Modification of specifications and plans.

(f) Unauthorized and condemned work.

(g) Disposal or use of materials found on the work.

(h) Character of workmen and equipment.

(i) Suspension of work.

(j) Laws to be observed.

(k) Necessary permits and licenses to be secured by the contractor.

(l) Sanitary provisions.

(m) Public convenience and safety.

(n) Public appurtenances not to be injured.

(o) Contractor's responsibility and risk as to work.

(p) Protection of life and property.

(q) Progress of the work. Conditions under which supplementary service may be undertaken.

(r) Default and annulment of the contract.

(s) Final cleaning up.

35. Special Provisions and Details.—Under this heading are placed such provisions and details of work to be done as pertain

to the particular contract proposed and are not common to the general specifications.

(a) Work to be done. Schedule showing locations of the items of work together with estimated quantities. Statement that the estimates are approximate and are given as a basis of calculation upon which the award of the contract is to be made.

(b) Changes in amount of work. Often an unfair provision is inserted that the Engineer reserves the right to increase or diminish the amount of work as he may deem necessary. An approximate estimate should have some degree of accuracy. A 10 or 15 per cent limit, depending upon the character of work, should be placed on changes except such as may be made through mutual agreement.

(c) Extra work incident to paving and for which no price is named in the proposal. To be paid for as far as practicable in accordance with a list of unit prices. Otherwise, on a cost plus a percentage basis.

(d) Time stipulations.

(e) Liquidated damage clause. Must be made evident that a deduction is not a penalty. If it is the policy to use this clause in all contracts and with standard deductions, it may be included in the "General Stipulations."

(f) Materials furnished by the city. It is often of advantage to a city to furnish certain materials. When this is done, full responsibility should be willingly accepted by the city for any delay caused the contractor thereby.

(g) Patent fees and royalties. On some classes of work it may be required that the contractor protect the city from claims. On others the city may desire to assume all responsibility under its specifications. However, if a city adopts one policy for all classes of work, the Patent clause may be included in the "General Stipulations."

(h) Payments (time, etc.).

(i) Any additional clauses thought to be necessary.

36. Construction Details.—Specifications relating to each type of construction may be drawn up under two general headings:

Materials.

Construction Methods.

These specifications should be prefaced with paragraphs describing in general terms the type of construction and, at the end, there should be stated the basis of payment.

PART II
PLANNING AND DESIGN

CHAPTER IV

THE STREET SYSTEM

37. The Influence of Zoning.—The necessity of city planning is now generally realized. One of its elements is zoning by means of which the matter of chance is largely eliminated in both the layout and paving of streets. Because of zoning it is certain that a given section of a city will be occupied by a definite class and size of buildings; and, therefore, streets may be planned to meet their specific needs in accordance with a well defined policy as to character of paving, and relative widths of roadways, sidewalks and parkings.

Narrow car-line streets in many of our cities illustrate the unsatisfactory conditions that result where city planning does not exist. For paving the usual car-line street a type should be chosen favorable to the passenger vehicles that frequent shopping districts since the logical development of such a street is retail business. If the pavement is not suitable a great deal of the street's advantage for business is lost, and its development is retarded. If its width is inadequate, trucks, automobiles and cars are forced to trail behind each other and the speed of all is reduced to that of the slowest and the result is waste of both time and money.

38. The Purpose of a Highway Plan.—Another important feature of city planning is the highway plan which has been previously mentioned, being one of the permanent records of the Bureau of Highways (see Chap. II). There are three plans that have influenced city layouts in the United States. That by William Penn for Philadelphia, known as the checkerboard plan; that of the commission headed by Gouverneur Morris, called the New York gridiron plan; and that drawn by Major L'Enfant for Washington. In addition there is the circumferential plan upon which many old-world cities are based. Notwithstanding adverse criticism that all these schemes have received from time to time, adoption of some of their general principles is well worth while. A rectangular plan need not be rigid but may be adapted to the terrain. State and county highways may be developed

so as to become main arterial routes of the city. Diagonal streets need not be straight for extremely long distances. Instead of indiscriminately cutting through hills and over valleys they may be laid out so as not only to facilitate traffic but also to aid real-estate development and to simplify the drainage of the entire city.

A highway plan is but a paper scheme. It is the duty of the engineer to give it life; to lay out the roadways, the sidewalks and parkings, to establish grades and to improve the streets so that they will best meet the needs of the city. In carrying out this work much stress is today laid on the preservation of the beauties of nature. This, however, must be done with caution since, in general, there are two main reasons for the existence of a city; the encouragement of business and the economic accommodation of large numbers of people within a relatively small area.

39. Width of Streets.—The width of streets is one of the fundamentals vitally affecting the expansion of cities, and, while



FIG. 7.—A street of detached homes marred by the occupation by an apartment house of what should be reserve width. Further development of the street is restricted because of the narrow limits thus established.

it is a mistake to make streets too narrow, it is also a mistake to make them too wide. A large portion of the area of a city is occupied by streets—the average is undoubtedly above 30 per cent of the total area—and, if they are unnecessarily wide, there is a waste of land that would otherwise be available for buildings. A street is the full space from building line to building line.

Normally, this width is occupied by a roadway, curbs, tree spaces, sidewalks, and the parkings or terraces in front of the buildings. Space other than that used for vehicles and pedestrians is extra or reserve width. It is provided, for one reason, as a matter of civic pride or to add beauty and comfort, and, for a second reason, to permit expansion of roadway and sidewalk width for future traffic. It is necessary that there be municipal control over this reserve width which is best had by complete ownership. If the reserve width is not so owned, structures thereon should be limited by building restrictions. Figure 7 pictures a case where, because of lack of foresight in this matter, the side of a large apartment house projecting 20 ft. in front of the normal building line spoils the residential character of a street. No one desires to build fronting on such a narrow roadway and restricted sidewalk. The roadway and sidewalk cannot be widened since no condemnation jury could find sufficient benefits to justify cutting through the apartment, and therefore improvement of the street is at a standstill.

40. Classes of Streets.—Streets may be divided into three classes depending upon their character:

Rapid Transit Streets.

Traffic Highways.

Local Streets.

In each class streets may vary in width according to their relative needs. The use that can be obtained from a given width of roadway depends upon the width of vehicles and this latter, except in the case of street cars should be limited to not more than $7\frac{1}{2}$ ft. Permits for wider vehicles might be granted subject to restrictions as to routes to be followed and time of day passage is to be made. The length of vehicles in the near future will also need restriction especially if the use of six-wheeled trucks and trailers develops. An over-long truck turning a corner takes up an unreasonable amount of space and is likely to damage with a swinging blow other vehicles.

41. Rapid Transit Streets.—The least width that is desirable for rapid transit streets is approximately 94 ft. In our older and larger cities car lines exist on streets of less width; but, today, these cities are spending huge sums because sufficient width was not originally provided. Experience shows that in laying out rapid transit streets provision should be made for double

tracks and, when the business character of the street has developed, there should be available a roadway of at least 54 ft. The space taken up by double tracks in various cities ranges from 14 to 16 ft., and, when a center line of poles for over-head trolley system is placed in the dummy, approximately 17 ft. is used. Several feet of space have to be allowed for over-hang of cars and clearance for passing motor vehicles. A total of 54 ft. is the minimum width permitting free passage between street cars and vehicles parked at the curb. This width allows the installation of car-loading platforms so that vehicles can pass between



FIG. 8.—Car loading platforms not only protect persons on foot but also help to speed the movement of traffic. This photograph shows a location being tried out by the use of temporary wooden platforms.

them and the curbs while cars are taking on and discharging passengers. Provision for car-loading platforms as illustrated by Figs. 8 and 9 is very important. Not only are persons protected but vehicles are given a freedom of movement that adds greatly to the traffic capacity of the street. Twenty-foot restrictions from curbs to building lines should be provided on either side of the roadway thus giving a total minimum street width of 94 ft. For business purposes, sidewalks should be paved completely from curbs to building lines with the exception of properly located tree spaces 4 ft. wide next to the curbs.

Allowances of 9 or 10 ft. for each line of street cars, 8 ft. for moving vehicles, and 7 ft. for parked ones are sometimes used

in designing roadways. These assumptions give a total roadway of 48 or 50 ft., which actual practice shows does not permit the comfortable and free use of the roadways between street cars and the curbs by two vehicles. Fifty feet is uneconomical and, as far as volume of traffic is concerned, is not much better than a 40 or 42-ft. width.

The addition of an extra foot or so on each side of the 54-ft., minimum especially when the track space is as wide as 17 ft., adds to the comfort of traffic and somewhat to safety. Further widening within a certain range, as for instance to 65 ft., is uneconomical; too narrow for three lines of traffic between the



FIG. 9.—A permanent installation. The lamp posts must be far enough from the track not to be hit by persons leaning from cars. In the base of each lamp standard is a red bull's eye as a warning to vehicles after dark.

track and the curb, and serving two lines not much better than a width closer to the minimum. Thus we have very definitely fixed for ordinary car-line streets a width of close to 94 ft. between building lines.

For streets of greater importance a step up to approximately 112 ft. is necessary which provides for a 72-ft. roadway and 20-ft. sidewalks with the trees in 4-ft. interrupted spaces. This roadway is wide enough to accommodate two streams of traffic between vehicles at the curb and the street cars. Actually, however, such use is curtailed because of the tendency of traffic to take the center of the available space in single file. An excellent plan for using a 72-ft. car-line roadway is to park cars at an angle or perpendicular to the curb rather than parallel thereto. This not only gives increased parking facilities but also allows

trucks to unload merchandise to advantage and the plan is looked upon with much favor by business houses abutting the street. At car-loading platforms vehicles may park parallel to the curb and still leave a free passage-way. Rapid transit streets of much greater width than 112 ft. are generally not favored by business people. Wide sidewalks place store fronts too far from the curbs and extreme roadway width can not be used to advantage. It is a better plan to provide sufficient 94 ft. and 112-ft. car-line streets rather than a lesser number of over wide ones.

42. Development of Rapid Transit Streets.—At times, street car lines tap sections of a city of such undeveloped character

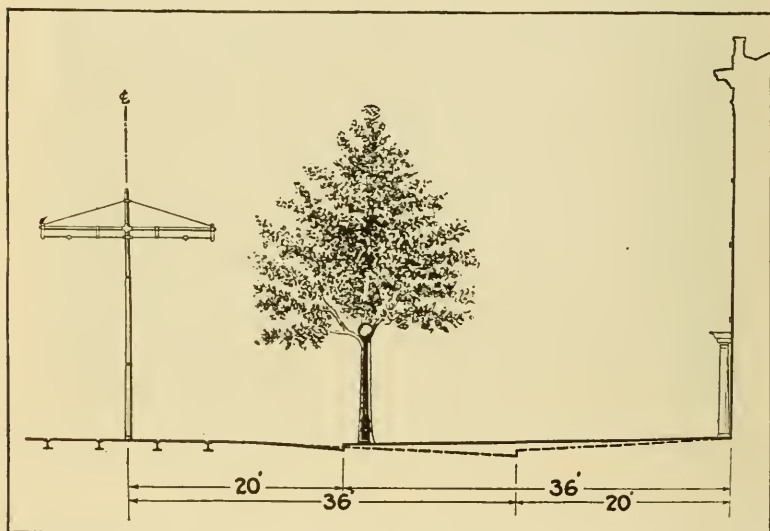


FIG. 10.—The widening of a 40-ft. center roadway on a 112-ft. rapid transit street requires changes in the existing roadway pavement and in the water and lighting systems. The sidewalk needs entire replacement and the trees are destroyed.

that a single track suffices for rapid transit and a narrow temporary roadway on one side of the track is sufficient for other traffic. The territory grows, double track is needed, residences abut the street, sidewalks and curbs are required, and an improved roadway. It is at this latter stage of early development that the highway engineer has to give most thought to the design of the street. It is to be remembered that the abutting residences are later to be replaced by business, but, because of the immature character of the street, a minimum width of roadway

of 40 ft. may be adopted. Less width is not warranted since safe and free passage of street cars and vehicles is endangered. While with 40 ft. one free line of traffic on either side is practicable, automobiles cannot pass between cars and vehicles parked at the curb. Furthermore, motors have to stop when cars take on or discharge passengers. These, however, are delays that may be considered justified because the total volume of traffic is relatively small.

There are certain disadvantages connected with a narrow development for the preliminary stages of a rapid transit street. Improvements when first installed should be placed, as far as



FIG. 11.—A too wide sidewalk and a congested roadway. Readjustment has been postponed year by year because of the heavy cost and the required destruction of trees.

practicable, true to permanent line and grade. Trees planted, when the character of the street is residential, should remain after the transition to business. Fig. 10 shows how the development from a preliminary central width requires changes in road pavement, curb, fire hydrants, lights, and sidewalks; and, in addition, completely destroys the trees. Fig. 11 pictures a street badly in need of readjustment. Vehicles are congested in the narrow roadway while the over-wide sidewalks are uneconomical and unsatisfactory to both the merchant and the pedestrian. Notwithstanding this, year by year, reconstruc-

tion has been postponed, due to the objectionable features entailed thereby, not the least of which is the destruction of the trees.

In Fig. 12 is shown a plan for the early treatment of a 112-ft. rapid transit street. This plan saves the sidewalks, fire hydrants, curbs, and trees, and causes no disturbance of the existing roadway when the full width of the roadway is needed. Traffic is better served than by a narrow central roadway the paved area of which includes the tracks. With a space available between the roadway and the car-line shrubbery may be planted thus

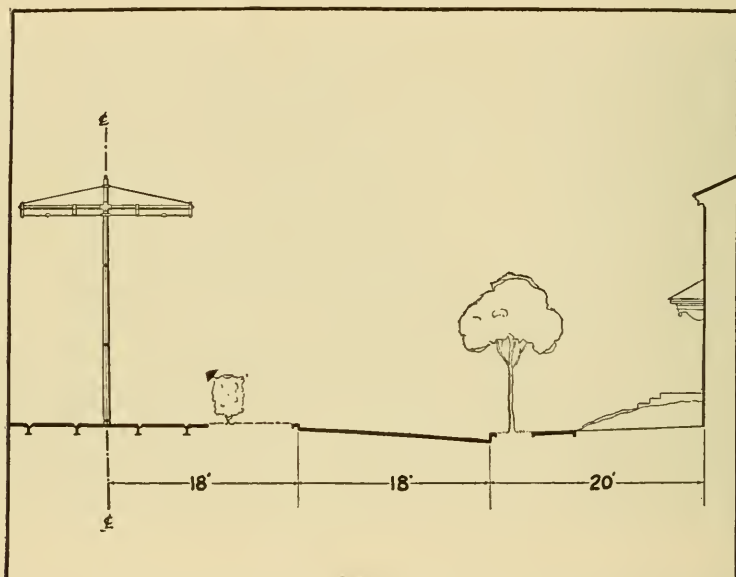


FIG. 12.—Early treatment of a 112-ft. rapid transit street prior to the extensive development of business. Eventual extension of the two 18-ft. side roadways to the full width of 72-ft. can be economically carried out.

beautifying the street and with much better effect than if its reserve width were set aside as front yards for the abutting property. Experience shows that over-large parkings in front of buildings bordering car-line streets are generally in an unkempt condition.

43. Traffic Highways.—Business streets require large volumes of traffic to be successful as such; and Rapid Transit Streets, if properly laid out, invariably become business streets. On the

other hand, Traffic Highways, though heavily travelled are not necessarily business streets. These highways exist primarily for hauling and motoring. They should afford convenient connections between residential, commercial and industrial districts and between the city and the surrounding country. Some may be portions of state trunk highways and completely by-pass the business sections of the city. Under certain conditions Rapid Transit Streets may very well also serve as Traffic Highways, but, when the full business character of the former develops, all interests are best served by having available separate highways for hauling and motoring.

A point of first interest as to Traffic Highways is the maximum economical width of roadway, and this limit is approximately 56 ft. Boulevards might be included in the general term "Traffic Highways" but need not always be subject to the same restrictions as regard traffic accommodation and economy. The plan for a boulevard may include such number and widths of roadways, walks and parkings as is limited only by the wealth of its promoters and the good taste of its designers. If more capacity is desired for a Traffic Highway than can be furnished by a 56-ft. roadway, relief is better obtained by the adoption of an additional one rather than by making the single roadway wider. A less width of roadway than 56 ft. is, in general, not justified for a Traffic Highway. For instance, on a 45 to 50-ft. roadway there is room for five lines of traffic but no decision can be made as to which direction the fifth line should take. Thus only four lines of traffic can be realized; a line at each curb and two central moving ones. The two central lines actually spread over enough space for three which is uneconomical. Unless a roadway permits two unhampered lines of moving vehicles in either direction it cannot satisfactorily serve as a Traffic Highway. If there is no need of vehicles stopping at the curb, a 38-ft. roadway will permit four lines of moving traffic and, in this case, gives the most economical Traffic Highway.

44. Sidewalks and Parkings on Traffic Highways.—The distance from the curb to the building line on Traffic Highways may vary with the character of abutting property. In industrial and some commercial zones, while but little sidewalk space is necessary, it is often desirable to have a wide space back of the sidewalk so that trucks can load at the buildings without obstructing either the roadway or sidewalk. When such space

is not available the end in view can be obtained by arcading the buildings as pictured in Fig. 13. On Sixteenth Street in Washington there is a 4-ft. tree space, then a 12-ft. sidewalk and,

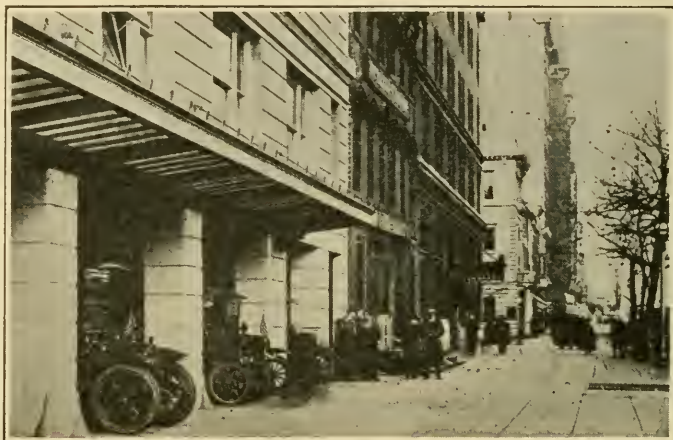


FIG. 13.—The business of loading trucks is here shown removed from the roadway. (*Courtesy of Washington Star.*)

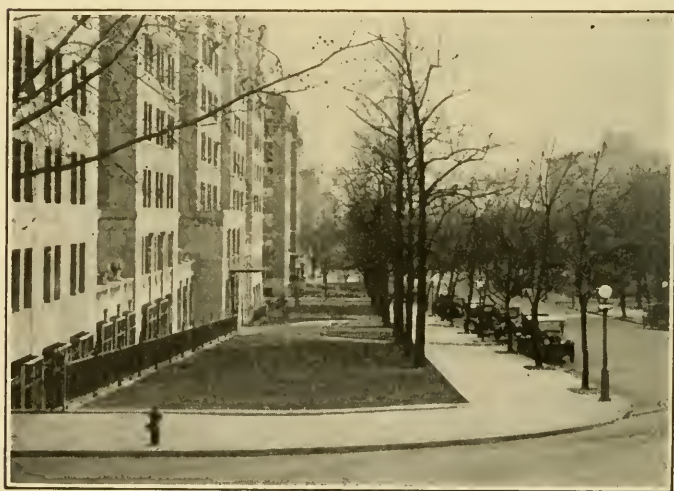


FIG. 14.—Forty-one feet from curb to building line. A width well adapted to apartment houses and residences bordering a traffic highway.

next to the buildings, a 25-ft. parking which gives a generous setting for residences or apartments as shown in Fig. 14. On

Fifth Avenue, Fig. 15, the 22½-ft. sidewalks are excellent for retail business purposes.

45. Traffic Highway Capacity.—The problem of pavement design to take adequate care of transportation's gross weight is today well in hand. To provide economically for the probable volume of transportation is a larger and more difficult problem. A strong pavement can readily be substituted for a weak one, but, unless plans have been exceptionally well made, it is seldom that



FIG. 15.—Fifth Avenue, New York City, prior to the installation of traffic towers. A large portion of the time but one-half the roadway was in use. (*Underwood and Underwood.*)

a wide roadway can be substituted in the heart of a city for a narrow one. Everything possible should be done to realize the full capacity of the roadway width that is available.

Fig. 15, a picture of Fifth Avenue, New York City prior to the installation of the traffic towers of today, illustrates that, with separate traffic regulation at each intersection, much of the time but one-half the available width was in use. One block

would be opened while the next one remained closed, leading to congestion on one side of the street with no traffic on the other half. The present system of treating vehicular traffic between Twenty-third and Fifty-ninth Streets as a unit, together with control of pedestrians, has doubled the capacity of the Avenue during rush hours. Today approximately 15,000 vehicles pass in 10 hr. The signal towers not only serve to start and stop traffic but also divide it, separating the north bound from the south bound. A division of traffic by center-line installations enforcing the "keep to the right" principle helps to realize the maximum capacity of a roadway as otherwise vehicles spread over too much space. It may be that at times there is a preponderance of traffic in one direction but, when the total is above 10,000 vehicles in 10 hr., there are at all times enough to justify center-line installations and enforcement of the "keep to the right of the center" rule.

On practically all Traffic Highways, parking at the curb or at least stopping in order to discharge passengers has to be permitted. These practices reduce the capacity of a 56-ft. wide, six-line roadway to less than 60 per cent of what it would be if there were no such stopping or parking. A 38-ft. wide, four-line roadway, if no necessity for stopping at the curb exists, affords, as has been stated, the most economical Traffic Highway of today. Even under these conditions an average traffic density during 10 hr. of 2,400 vehicles per hour or 600 per single line is seldom attained. In many cases it may be necessary to put into effect stringent special regulations relative to traffic, such as, for instances, prohibiting animal drawn vehicles on certain streets, or restricting coal and similar deliveries in congested areas to night hours. Interruptions to the constant and uniform progress of traffic, if not corrected, result in the ultimate expenditure of huge sums for additional roadways because the original ones fail to render the full service that should be realized.

46. Development of Traffic Highways.—The photograph Fig. 16, shows a newly laid out Traffic Highway. The amount of traffic using the roadway is increasing day by day. Abutting real estate has been put into shape for sale and houses are soon to be constructed. For the present, however, seldom or never are there more than two lines of traffic on the roadway. Under these conditions a high type of expensive pavement for the full width is not justified. One alternative is to use a cheap con-

struction, spreading the money thinly over a large area, as has been done in the case of the illustrated example. This gives a



FIG. 16.—Uneconomical treatment of a newly laid out Traffic Highway. Surfaced for the full width with a low priced pavement years before the time that provision needs to be made for more than two lines of traffic.

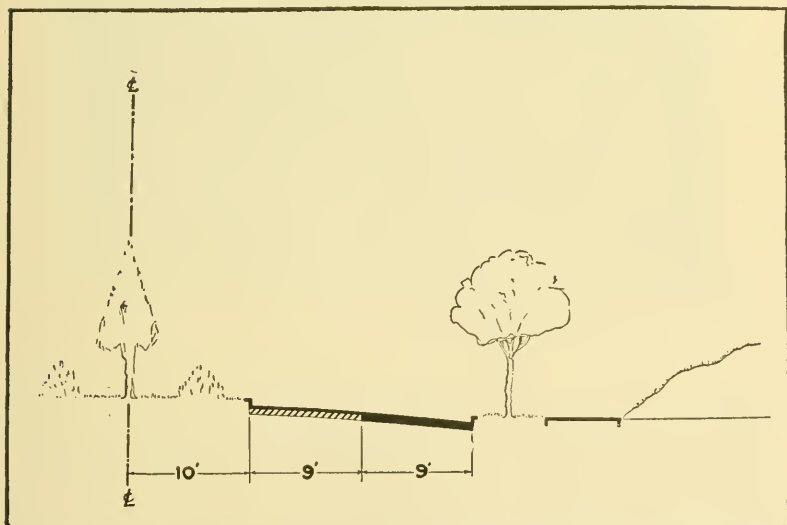


FIG. 17.—For the first improvement of a 56-ft. Traffic Highway two 9-ft. marginal strips of pavement with adjacent strips of cheaper construction should suffice. As traffic increases the development may be progressive until the entire 56-ft. width is paved.

surface with a probable life of 10 or 15 years, but with high yearly maintenance rapidly increasing in amount as the pavement

grows older and traffic increases. Furthermore, when a better type is demanded, the old pavement has little or no salvage value. A better plan is that shown in Fig. 17 the initial stage of which includes trees, curbs, 9-ft. concrete tracks next to the curbs and a cheaper construction bordering the concrete in order to permit turn outs. When houses are built, additional 9-ft. strips are necessary thus giving available widths of 18 ft. of concrete and permitting parking at the curb. These concrete roadways should be built on suppressed grades with sufficient curb showing to permit their utilization at later dates as bases for whatever may be the ultimate surface of the completed high-



FIG. 18.—Central parking on a Traffic Highway. When the volume of traffic justifies the removal of a parking of this nature the roadway width of 56 ft. is easily and economically obtained.

way. With a 56-ft. roadway the center 20 ft., may be set aside as parking, affording a treatment as illustrated in Fig. 18, until such time as traffic demands its replacement with paving. Progressive improvement of the street as outlined gives a smooth surface roadway from the beginning and with minimum depreciation and maintenance charges. The construction is paid for in installments commensurate with the volume of traffic that is served.

47. Local Streets.—The majority of the homes of a city are not located on the two classes of streets thus far discussed; Rapid Transit Streets and Traffic Highways, although some of the

latter in many cities are examples of magnificent residential streets. Most dwellings, however, are on streets the purpose of which is primarily only the service of the homes; and these streets, purely residential in nature, constitute most "Local Streets," and in fact probably 80 per cent of a city's total street mileage. Other Local Streets there are, such as those used for market places, water front needs, and other purposes, commercial or industrial. The requirements of these are so dependent upon the business to be satisfied that each case needs special consideration. There are also some residential developments for which



FIG. 19.—A 90-ft. Local Street divided for residential purposes into 30-ft. roadway, 6-ft. tree spaces, 6-ft. walks and 18-ft. parkings.

special treatment may be permitted subject to the restriction that there must be no interference with the proper extension of Rapid Transit Streets and Traffic Highways. A caution is necessary, however. Too often sub-divisions have been limited only by the imagination and selling ability of the real estate operator. Extravagant schemes have at times been laid out in the path of a city's natural growth, and, being unsuccessful, have greatly retarded expansion and progress.

It is to be remembered that Local Streets are used almost entirely for the benefit of the adjacent properties. Such streets

need not be continuous for long distances and their roadways may be of limited width. Eliminating some of the special cases that have been mentioned, a fair width for a Local Street may be set at 90 ft., divided for residential purposes into a 30-ft. roadway, 6-ft. tree spaces, 6-ft. walks, and 18-ft. parkings adjacent to the buildings, as shown in Fig. 19. This combination gives a very presentable street for either detached or row houses. The roadway width allows parking at the curb and sufficiently free passage of vehicles in either direction, considering the restricted local character of the street. For business purposes the division of a 90-ft. street may be a 50-ft. roadway with 20-ft. sidewalks.



FIG. 20.—A minimum width Local Street. Twenty-four-foot roadway, 3-ft. tree spaces, 4-ft. walks and 6-ft. parkings.

This width roadway permits diagonal parking at the curb, facilitates unloading from trucks, and still allows space for two lines of moving traffic in the center.

No Local Street used for residential purposes should be less than 50 ft. in width. Division of a 50-ft. street may be into a 24-ft. roadway, 3-ft. tree spaces, 4-ft. walks, and 6-ft. parkings, an example being shown in Fig. 20. The street has a good appearance and, while there is little or no grass space in front of the homes, the occupants are well satisfied. Experience shows that they have but little time to take care of parkings. There are

some advocates of a 16-ft. roadway as a minimum on the grounds of economy, but a 24-ft. width permitting parking at the curbs with room for the passage of only one vehicle in the center appears to be the least justifiable width.

48. Block Divisions.—Certain principles that have been stated are to be remembered in laying out city blocks: For some streets it is desirable to discourage traffic except that having to do with abutting property. The roadways of these streets should

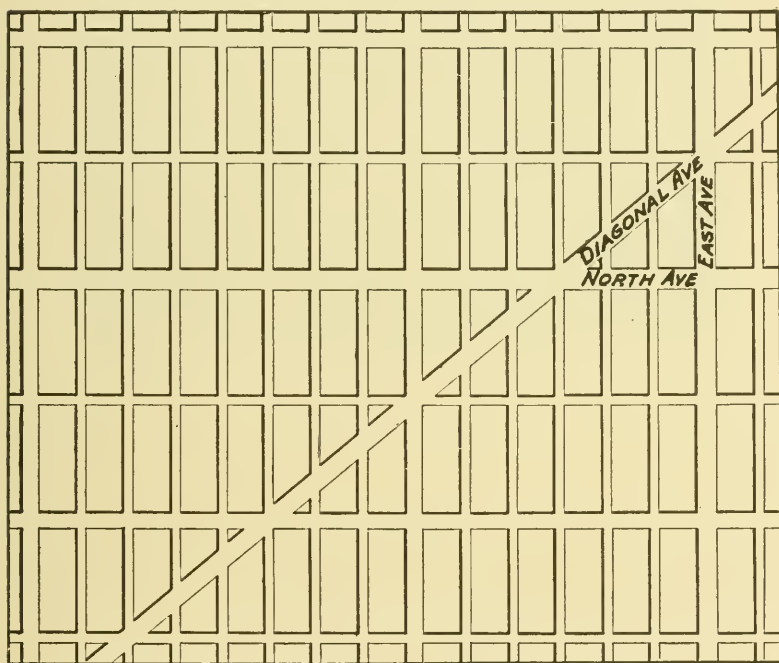


FIG. 21.—The short distances between cross streets along Diagonal and North Avenues and the intersections of three streets along Diagonal Avenue are objectionable.

be wide enough for local requirements only, and need not be continuous for long distances. For others, through traffic is a prime consideration and interruptions to safe and rapid travel should be a minimum. In Fig. 21 traffic on Diagonal and North Avenues is hindered by the succession of intersecting streets at short intervals and further, on Diagonal Avenue, by the fact that every fourth intersection is a junction of three streets. In Fig. 22 these objectionable features are corrected, at the same

time giving a more favorable sub-division into building lots. A city block may logically have a long axis and a short one. Long axes should border Traffic Highways and may be as much as 800 ft. in length, thereby giving good fairways between intersections. Thus traffic is favored and, at the same time, a maximum area of land for sub-division into high-priced lots fronting the Traffic Highways is obtained.

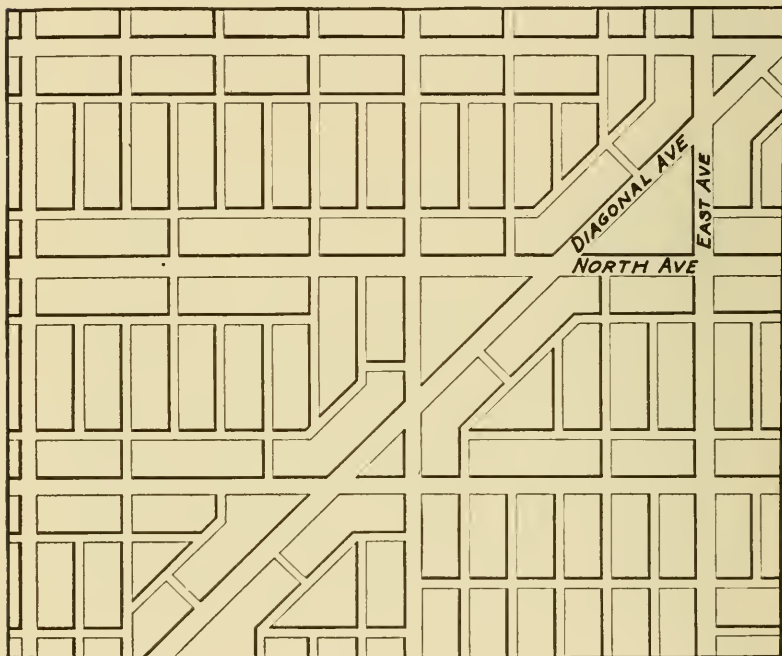


FIG. 22.—The objectionable features illustrated in the preceding figure are corrected in this plan. No more than two streets intersect at one point. On the avenues the long spaces between cross streets are an aid in speeding the movement of traffic. Nevertheless the plan is still basically rectangular.

49. Alleys.—The ever increasing use and popularity of motor transportation, in addition to affecting the design of roadways in the details of widths, grades and pavements, also influences many incidentals of the highway plan as, for instance, the alley problem in residential districts. Heretofore, the service rendered by alleys has been set against their cost and, while acknowledging their necessity for business areas, engineers have disagreed relative to residential districts. As shown in Fig. 23, alleys

make it possible to keep the objectionable features connected with the collection of refuse away from the fronts of houses. Also a good location is provided for the poles of utility services. Not only on these usual counts do residents desire alleys but



FIG. 23.—Alleys not only provide for the poles of utility services, and make it possible to keep the objectionable features connected with the collection of refuse away from the fronts of houses, but provide for the convenient location of garages.

today convenient access to garages on the rear of lots or under the backs of houses is demanded and the balance is thrown definitely in favor of alleys, the least practicable width being 16 ft., and the maximum necessary being about 20 ft.

CHAPTER V

THE PROBLEM OF SELECTION

50. The Selection of Roadway Pavements.—While animal drawn vehicles are still used for certain purposes, they now constitute only a small part of the traffic on city streets. Except as they slow up traffic and thus limit its volume, they are a minor factor in city pavement design. Motor traffic is the controlling factor. For its accommodation, pavements must be strong enough; for economy and for the comfort of passengers and of residents and businesses along the streets, the pavements must be smooth and dustless. In any particular case the selection of the type from among those which fulfill these conditions is determined by the traffic requirements and by the limiting costs. Any one of several types may give good service; the problem is to choose one which will give good service and whose cost will be reasonable.

51. Economy and Service.—Known factors are the amount of money available for paving projects, the cost of the different kinds of pavements and the cost of maintenance. In some cities there are still earth streets with high crowns and side ditches, muddy in winter and dusty in summer. Sometimes these streets are dressed with cinders but the resulting black dust is objectionable. Gravel surfaces are common, and in practically all cities there are many miles of waterbound macadam. The problem is to determine how long to maintain these inferior types and when they must be replaced by the strong, smooth dustless pavements adapted to modern traffic requirements. The Engineer of Highways must know, not only how to pave but what to pave. He does not do his whole duty when he merely directs the expenditure of money appropriated for paving. He must do more. He must initiate paving projects, set forth convincingly their merit, make reliable estimates of their cost, show conclusively the resulting economies and especially the vital necessity for a well-considered continuing paving program.

52. Making up a Paving Program.—Whenever appropriations for municipal operation are under consideration it is usual to

make comparisons with costs of government in other cities. Erroneous conclusions are common since there are many social, political and economic factors, one or more of which may be neglected in the comparisons. Because cities are equal in population it by no means follows that their annual budgets are likewise identical. Per capita municipal expenditures for street improvements vary from close to \$1 to four times that amount. There are in existence different methods, some fair and others most unfair, of directly assessing street improvements. Real property values in various cities are computed by different methods. The acreage of cities of equal populations and also real property values per acre and per capita differ widely. There are so many factors that cannot be weighed that a worth while comparison between cities is practically impossible. To date no universal unit of measure has been devised that can be applied to a city to show whether or not it is adequately paved. Conditions in each city have to be separately studied and a project can be drawn up only after inspecting the streets in detail, listing deserving items, and balancing the costs against the benefits to be obtained.

In presenting an estimate of what is necessary in the way of improvements an effort should be made to prepare the data in such a form that every citizen will be able to understand it. A project should look into the future, extending over several years. Recently there has been a general holding back on appropriations for pavements. An effort should be made to point out that the longer neglect continues the more difficult and costly it becomes to catch up. Two suggestions along these lines are given in the following paragraphs.

It is practicable to show, for any one city, how it has grown or prospered during recent years; whether or not the construction of new pavements has kept pace with this growth; if not, the construction necessary to bring the paving up to date, and further, the amount that should be done each year in order to keep up with the city's growth. From assessed property values, knowing the methods and conditions under which assessments have been made, there may be tabulated the real property value of a city for each year. These values covering any period of time give a very fair idea how a city has grown, for example, as is shown in Fig. 24 where each black dash along the axis of abscissas represents the real property value of the designated year. Continu-

ing these values into the future with the same rate of increase established by previous years the abscissas in this figure show for the city represented, its growth from 1895 to 1925.

The construction of new pavements is required for streets on which new buildings have been erected and also for streets that serve as connections between these newly built up sections of a

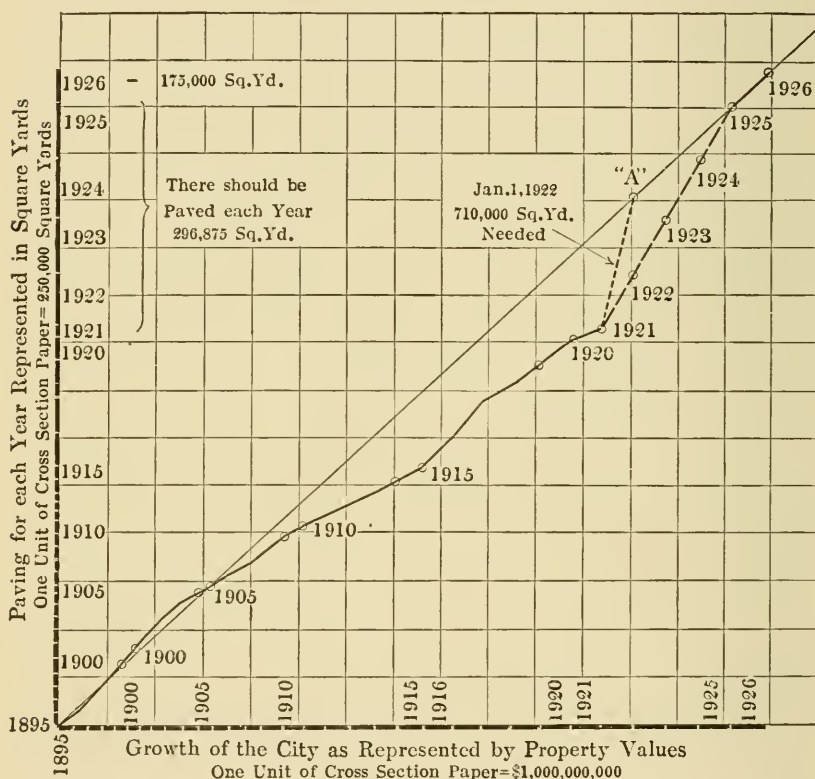


FIG. 24.—A paving program, providing for those deserving streets that have not been paved in the past, and for those that will be required in the future to meet the needs of a growing city.

city and the older sections. New paving should not be confused with repair work and the reconstruction of surfaces on existing pavements. Corresponding to the abscissas in Fig. 24, are plotted along the axis of ordinates the square yards of new pavement constructed yearly. The broken line from 1895 to 1921 is located by these coordinates and it shows what has

actually been done by the city in constructing new pavements. When insufficient, the curve drops; when more nearly a proper amount was undertaken the curve rises.

In the city used in this example there were 710,000 sq. yd. of new pavements needed on Jan. 1, 1922. Plotting this amount gives a point A. Connecting this point with the origin gives a line which shows the path that should have been followed by new street construction if year by year sufficient money had been available to pave all deserving streets. The actual path followed

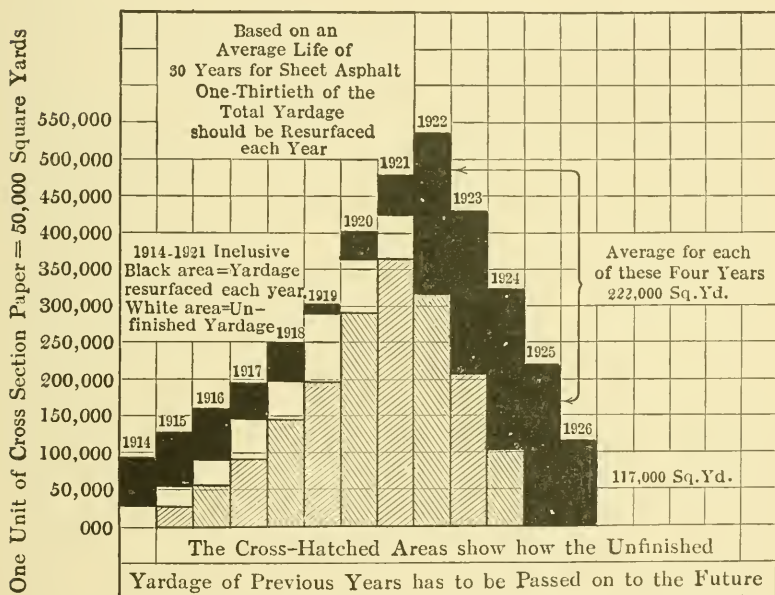


FIG. 25.—A resurfacing program, calling for the improvement of those streets that have been neglected in the past and, at the same time, providing for the needs of the future.

is far below normal and it is apparent that the longer recovering is postponed the more difficult it is going to be to get back to normal. Even now an extraordinary effort, probably beyond the ability of the city, would be necessary to recover in 1 year and reach the normal line at the point A. The recovering would be less burdensome if distributed over 4 years, constructing, as shown by the diagram, 296,875 sq. yd. of pavement each year. Thereafter, the normal line could easily be followed; for instance in 1925 the amount would be only 175,000 sq. yd.

Similar information for the people and those appropriating funds can also be shown in a simple manner in the case of sidewalks and alleys, maintenance and the reconstruction of worn out pavements. The diagrams may be of various forms, for example Fig. 25, is a suggestion explaining a resurfacing program. In 1915 the sheet asphalt pavements in the city to which the diagram refers were in first class condition. Records of preceding years show that under the conditions peculiar to this city the average life of sheet asphalt is about 30 years. Therefore, if these pavements were to be continued in a satisfactory state, each year one-thirtieth of the total yardage should have been stripped from the concrete base and replaced with new. Instead, in 1914 only that portion of the one-thirtieth shown in black was resurfaced. That shown in white was neglected and carried over to the next year as shown by the cross-hatched area. Each succeeding year only a portion of the year's one-thirtieth was accomplished and the accumulated neglect is shown by the growth of the cross-hatched area.

In order to substantiate the fact that there really existed on Jan. 1, 1922, a necessity for resurfacing all the yardage represented by the diagram (368,650 sq. yd. left over from previous years as shown by the cross-hatched area plus 61,139 sq. yd. left undone in 1921 as shown by the white area, or a total of 429,789 sq. yd.) a canvass of the city was made and 147 separate street items were listed having a total area of 429,700 sq. yd. The average age of the sheet asphalt on the streets represented on this list was above 30 years and the physical condition of the pavements was so bad that resurfacing was clearly necessary.

In order to overcome the neglect of past years a program should be followed calling not only for the complete resurfacing of the one-thirtieth portion each year but in addition a fair share of the accumulated unfinished yardage of previous years. Assuming a resurfacing program that would call for a return to normal in 4 years, an average of 222,000 sq. yd. would have to be carried out each year as shown in black up to and including 1925. Thereafter there should be no postponed or unfinished work, and each year one-thirtieth of the year's total yardage would be resurfaced; for instance in 1925 the amount would be approximately only 117,000 sq. yd. A request for funds supported by easily understood diagrams showing a logical project is worth many times a mere statement as to the amount of money desired.

53. Financing a Program.—There are two extremes of thought concerning highway financing. The one favors the “pay as you go” or cash system on the theory that we should bear our own burdens; that demands are ever enormously increasing, and that future generations should not be called upon to assume liabilities other than those which they themselves incur. The other favors the spreading of original costs over a very long term, at least 50 years, on the assumption that many of the features of a roadway are permanent and that those which are not may be adequately cared for by current expenditures for maintenance. A sound and conservative policy midway of these extremes requires that all previous obligations be retired prior to starting any reconstruction or rebuilding of a roadway. This policy establishes rather definitely a 20-year bond term for high class city pavements. However, borrowed money should always be paid as soon as funds can be raised without unreasonably burdening or oppressing the citizen, and if bonds can be retired in less than 20 years their payment clears the field for further construction that may today be unforeseen. On the other hand, if an improvement is of such pressing necessity that the locality cannot prosper without it, insistence on as short a term as 20 years should not be allowed to prevent the construction.

While running repairs should be paid from current tax levies, the issuance of bonds to be retired in about the life of the pavement makes possible the economic handling of programs of new construction and resurfacing. Taxpayers should not be made to pay the entire cost of an improvement at one time, but by installments, each commensurate with benefits derived during the period which it covers. A bonded debt includes the payment of interest but this should not be considered as increasing the ultimate cost of an improvement. Instead, this system permits the taxpayer to invest for his own account money which he otherwise would have to pay out and he can generally make it earn more than the bond interest rate.

Bonds may be retired by periodic reductions of the principal or by means of a sinking fund established by setting away at compound interest certain amounts at the beginning of each year or at other set times. The curve in Fig. 26 shows the payments that would be necessary at the beginning of each year, with money at 4 per cent, in order to retire sinking fund bonds of various terms; for example, the curve shows that a 20-year

sinking fund \$100 bond would require 20 equal payments of \$7.23 in order to pay interest and retire the principal. As the term decreases below 10 years, the curve becomes very steep, the payments relatively large and burdensome, and a satisfactory measure of benefit is not derived from the bond system. Beyond 20 years the curve becomes very flat. A 50-year term is $2\frac{1}{2}$ times as long but calls for annual payments only one-third smaller than a 20-year term. Thus there are two reasons for the frequent choice made of a 20-year term; its favorable loca-

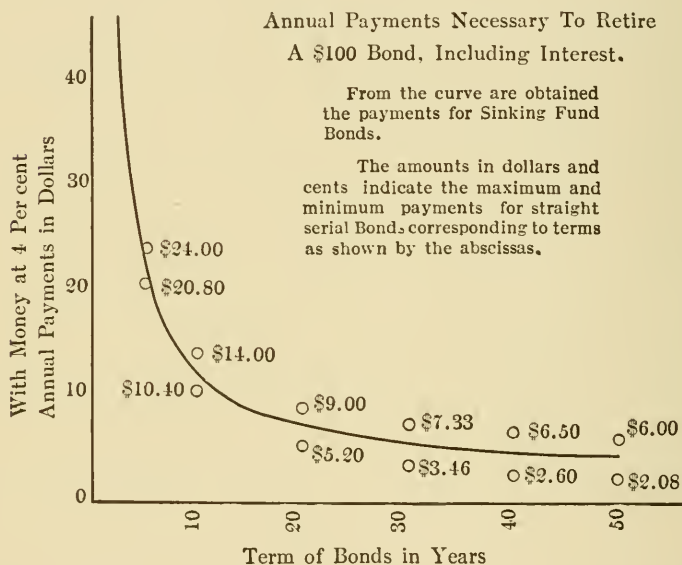


FIG. 26.—This figure illustrates the difference between the sinking fund type of bond and the straight serial form. It also shows that, for terms of less than 20 years, the annual payments rapidly become very large, and, for terms of more than 20 years the payments differ by but small amounts.

tion on the "bond curve" and the fact that it meets the desire that bonds should have no longer life than that of the pavement.

The serial form of bond, by which plan a definite portion of the principal is periodically retired, has come into much favor. There are various modifications of this plan, as for instance the deferred payment form, whereby no principal is retired until a certain period, usually 5 years, has elapsed. With money at

4 per cent, the amounts, in dollars and cents in Fig. 3 show the range in payments including interest that would be necessary for straight serial bonds for example, in the case of a 20-year, \$100 straight serial bond, the first payment would be \$9 and payments would decrease regularly until the twentieth which would be \$5.20. The early payments are larger than for a sinking fund bond; the later ones smaller. The cost to the citizen under various plans should be equal, since funds whether private or public should earn interest: and gradual payment or gradual accumulation for a single payment should accordingly come to the same thing. However, the serial form has a very distinct advantage in that it requires no administration of a sinking fund. Many persons hesitate to start sinking funds to pay private debts because they doubt their self control in handling such funds. In the case of a public debt it requires sound financial methods to handle a sinking fund successfully. Even under the best administration, often a much less interest is earned than is paid on the bonds. This pushes the curve, Fig. 26, upwards and the annual payments made in accordance with the sinking fund plan thereby approach closer to the maximum that would be required by the straight serial form of bond.

54. Annual Cost of New Pavement.—With money at 4 per cent and assuming, for example, that a satisfactory pavement and curb can be constructed for \$3 per square yard, with 2 cts. per square yard for equated annual repairs, the annual cost of an improvement having a probable life of 20 years would be as follows:

12 cts. per square yard annual interest.
2 cts. per square yard equated annual repairs.
10 cts. per square yard depreciation annuity.
24 cts. per square yard annual cost.

The amount of the depreciation annuity is obtained by use of Table I.

Stating the cost of a pavement and the items that make up the total as so much per square yard per year aids the engineer in passing upon three important factors that bear upon the demand for new pavements. These are the cost of maintenance, the attitude of abutting property owners, and the traffic cost as determined by the character of the paving.

TABLE I.—THE SUM OF MONEY WHICH MUST BE INVESTED AT THE BEGINNING OF EACH YEAR FOR THE LIFE OF THE PAVEMENT TO AMOUNT TO \$1 AT COMPOUND INTEREST AT THE END OF THE PAVEMENT LIFE IN YEARS

Life in years	Interest at 2 per cent, dollars	Interest at 3 per cent, dollars	Interest at 4 per cent, dollars	Interest at 5 per cent, dollars	Interest at 6 per cent, dollars	Life in years
10	0.08953	0.08469	0.08009	0.07572	0.07157	10
15	0.05669	0.05220	0.04802	0.04414	0.04053	15
20	0.04035	0.03613	0.03229	0.02880	0.02565	20
25	0.03061	0.02663	0.02309	0.01995	0.01720	25
30	0.02417	0.02041	0.01714	0.01433	0.01193	30
40	0.01623	0.01288	0.01012	0.00788	0.00610	40
50	0.01160	0.00861	0.00629	0.00455	0.00325	50

55. The Cost of Maintenance.—Whether streets are paved or not, some money must be spent for maintenance: For unpaved streets the maintenance cost is relatively high and as traffic increases it rapidly mounts and ultimately there comes a time when it is decidedly more economical to put in place a modern pavement. It is not uncommon to find on some residential Local Streets more than 20 cts. a square yard per year being spent for maintenance. This includes the cost of cinders or gravel to give some bottom to the roadway, labor in the winter months so that vehicles will not be completely stalled in the ruts, and sprinkling in the summer to alleviate the dust nuisance. On Traffic Highways with worn-out roadways expenditures of 30 cts., and even as much as 40 cts. per square yard are common. With the cost of a new pavement reduced to an annual basis, the economy of substituting new construction for extravagant maintenance becomes apparent at once. The problem, however, has a broader aspect than that of pure maintenance. On a residential street, irrespective of whether much or little is spent in maintaining an earth roadway, the results may be unsatisfactory from the residential view point. On a Traffic Highway, even though 40 cts. per square yard per year is spent in maintaining a worn-out roadway, the service rendered transportation may be unsatisfactory.

56. The Attitude of Abutting Property Owners.—The problem of the Engineer of Highways in deciding when a street should be paved is made easier if the paving assessments on abutting property are on a proper basis. If assessments are too heavy, residents instead of desiring pavements clamor for an extravagant expenditure of non-assessable maintenance funds. If assessments are too small the construction of pavements is agitated long before a neighborhood is sufficiently built up to warrant the expense. In the case of a street where the interest of the general



FIG. 27.—Not only is improvement of the roadway on this street desirable from the standpoint of economy; the residents demand improvement on the basis of appearance and comfort; and in a case of this character, these are important factors.

public is large, for instance, a Traffic Highway which has a wide roadway in order to accommodate large volumes of traffic, and for which a high priced pavement is necessary, about two-thirds of the cost should be paid from general taxes and one-third be charged against the abutting property. On the other hand, on a residential Local Street where the pavement is largely for the benefit of those living along the street these proportions should be reversed with probably two-thirds of the cost charged against the property. As an illustration, reference is made to Fig. 27. The residents on a Local Street of this character desire a pavement and curb on two counts; appearance and comfort. While these elements cannot be weighed, the residents are generally willing

to pay a fair share of the cost of an improvement in order to obtain them; and especially is this true if, by means of bond issues, payments can be made in annual installments. In the case of a street, as shown in this picture, 30 ft. wide and with house front-ages of 21 ft., but 35 sq. yd. of pavement pertain to each dwelling. With a sinking fund form and money at 4 per cent there would be an expense for bond retirement of 22 cts., per square yard in the case of a \$3 per square yard improvement, having a probable life of 20 years. Therefore, the cost per dwelling would be 35 times 22 cts. or but \$7.70 annually; and, if it is assumed that one-third is paid from general taxes, the remainder or \$5.13 would be charged against the property.

57. The Cost of Transportation.—During the rapid growth in recent years of motor traffic, city street improvement has not in general kept pace with state road improvement. Too often, on trunk line highways, upon arrival at city limits, a ride over a smooth country road is exchanged for a rough ride over city streets. The chart, Fig. 28, shows the increase in motor vehicles and in state highway funds since 1910. The number of motor vehicles today is close to 1 for each 10 persons. This ratio will probably not change much and accordingly, the motor vehicle curve will rise in most part only as population increases in the future. From the bottom curve in the diagram, it is seen that there are between six and seven times as much state highway money available today as in 1910 and there is every indication that funds will be available in large sums for some years to come. In many cities expenditures for roadways are today smaller than they were ten years ago. In state road work there is a realization of the relationship between motor vehicles and roads and the situation is being met successfully.

It would help city officials to appreciate the need of new pavements if there could be plainly shown the large burden of excess expense placed on motor vehicle operators because of worn-out roadway surfaces. In some cases the influence of those daily riding over a street may be sufficient to demand and obtain a new surface on the ground of comfort alone. Cities at times are proud of certain streets and civic pride may demand a new surface from the standpoint of appearance alone. In the majority of cases, however, economy should be the decisive element. It has been estimated that in the United States \$12 are spent on the vehicle each year where \$1 is spent on the road. It is to be

hoped that in the near future data will be available showing how much more it costs to operate vehicles over a worn-out surface than over one in prime condition, not only the extra cost of fuel,

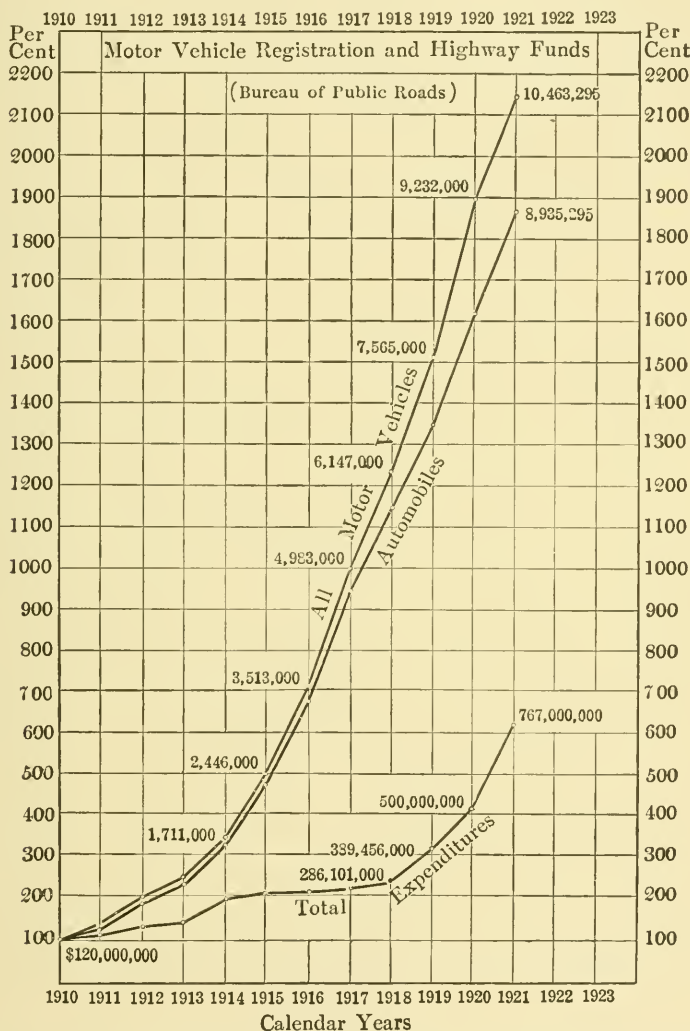


FIG. 28.—In state highway work, since 1918, a strenuous effort has been made to meet the needs of motorized traffic. There are prospects of even greater effort in the future. Many municipalities have failed to meet the emergency.

tires, etc., but the larger repair bills, the greater depreciation and the loss of time.

How such transportation costs enter, may be explained as follows: In order to include passenger cars, take gross load as a basis, that is, vehicle weight plus load weight, and the average cost of operation is somewhere in the neighborhood of 8 cts. per ton-mile. Let it be assumed that somewhat less than 500 tons daily pass over a given mile of worn-out roadway for each yard of width; that is, approximately 176,000 ton-miles per yard width per year. If it costs but 1 ct. a ton-mile more to operate over this rough roadway than over a good one, then the yearly excess expense is \$1,760 per yard width of roadway, or \$1 per square yard, a sum probably five times as much as the annual cost of a new surface. Thus, in order to judge from the transportation standpoint whether or not a new pavement is warranted, there should be known; the traffic tonnage per yard of roadway width, and the cost per ton of carrying this traffic.

58. Bituminous Treatment of Old Roadways.—There may exist on many Local Streets of well established residential character macadam or gravel roadways which, while satisfactory years ago, are objectionable under the motor traffic of today. If the macadam or gravel is of good quality such roadways, as long as there is to be no great volume of traffic can be made satisfactory by bituminous surface treatments. These existing pavements may be considered as paid up investments and, therefore, in the "annual cost of pavement" no charge need be made for interest nor for depreciation. The only expense that should be considered is that of maintenance; and, including periodic bituminous treatment and all repairs, this, for a fairly long time, should not exceed 10 cts. per square yard per year. As long as a satisfactory pavement can be obtained at this low cost it is apparent that it pays to make every effort to conserve these old paid up investments rather than to discard them and purchase entirely new pavements at more than double the cost. Though good service can thus be obtained from old gravel and macadam the choice of either for new construction would be very doubtful; this matter will be discussed in subsequent paragraphs.

59. One Course Concrete for Residential Local Streets.—While the character of available materials and of other elements that enter into the details of construction play a large part in making a choice it is generally true that a one course concrete pavement fulfills the requirements of a Local Street of a resi-

dential character more economically than any other type. Neither waterbound macadam nor gravel gives the satisfaction to residents that a clean smooth surface does. New construction of macadam and gravel can be improved from the residential viewpoint by bituminous surface treatment, thereby doing away with dust, but then the question of economy arises. Interest and depreciation annuity may be smaller but a larger sum for equated annual repairs generally makes the total annual cost more than that for concrete. Another objectionable feature in the use of gravel or macadam is the difficulty of making good and lasting patches when repairing cuts made for plumbers' connections and other purposes.

A bituminous macadam constructed by the penetration method may compete with concrete as to first cost and also render good and economical service for a number of years; but it and cheaper types lose in comparison with concrete on the following grounds: All one course pavements eventually wear out. In the case of concrete, after a reasonable number of years of service as a one course pavement, it can be topped with a wearing surface and thus protected. As a base it should outlive many wearing courses which periodically may be stripped from the base and replaced. Concrete serves as a base better than any of the other types of pavements just discussed and, in fact, should be accepted as a permanent investment. In other words, the taxpayer, in paying for a concrete pavement in 20 years, is buying an article with a substantial value at the end of that period. Assume that as a base for future wearing surfaces the concrete has a worth of \$1.50 per square yard and that resurfacing will take place at 20-year intervals. This \$1.50, with money at 4 per cent, is worth 6 cts. per year on account of interest saved plus 5 cts. per year for depreciation annuity. Thus, the taxpayers, in making a paid up base available, save nearly the equivalent of 11 cts. per square yard per year, which would otherwise have to be paid if the base had to be renewed at the end of the 20-year period.

60. A Thickness of 6 In. Sufficient.—The relative cheapness of a concrete pavement is due to several economies that may be practiced under the favorable conditions existing in cities. Hydraulic cement concrete has been used as a base for city pavements for almost a half century. There are many instances of lean concrete bases that have been resurfaced several times

and experience shows that a properly constructed concrete base may be considered a permanent installation. While extensive experience with one course concrete has been had but for a short time, practically only since 1914, it is believed to be sufficient to show that normally a 6-in. one course pavement of rich concrete should give 20 years of service on a Local Street and should thereafter be available as a permanent base for other wearing surfaces. While the thickness should not be less, 6 in. is sufficient to withstand unlimited light traffic; and heavy trucks, which occasionally have to use Local Streets, should cause no excessive damage within the expected service life of 20 years. Under the heading, "Sub-grade Drainage," Chap. VI, it is brought out that the thickness of pavements should be increased over small local areas where the soil is abnormally wet and cannot be drained by gravity. To meet such conditions, seldom or never is it necessary to adopt a greater increase than 2 in.

61. Neither Reinforcement nor Joints Necessary.—Other elements than the direct loads, for instance moisture and temperature variations, affect one course concrete pavements to a considerable extent. Shrinkage causes cracks which are mostly in a transverse direction. Warping of a concrete slab, one part being in close contact with the sub-grade while another part is entirely free from support, undoubtedly leads to many of the longitudinal and irregular cracks encountered in roadways. In country roads longitudinal cracks often open considerably since the friction on the soil is not sufficient to hold in place the concrete on either side of the crack. In city streets the curbs hold the pavement in place and the cracks do not open to an objectionable degree. Cracks when properly cared for are not bothersome to the traffic passing over a roadway. In trying to prevent cracks, modified beam formulae are sometimes applied to pavement design, but this seems to be an unnecessary refinement, because the separate pieces into which a pavement breaks lie in close contact with the underlying soil and loads are distributed over such an area that the result is well within the supporting power of the sub-grade. Cracks are easily and inexpensively waterproofed and protected with bituminous filler. Also the edges of adjacent areas of concrete at cracks generally dovetail, so that some mutual support is obtained. At construction joints, made for instance at the end of a day's

work, this mutual support may be obtained by the use of short dowels, which prevent the lifting or sliding of the slabs at these points. With cracks properly filled and treated there is no serious deterioration due to frost action, nor breaking and spalling of the edges under traffic.

On country roads triangular pieces of concrete often break off where transverse cracks meet the edges of pavements. Making a pavement thicker at the sides than at the center lessens the seriousness of these breaks; this may also be achieved by using inverted curbs. In city practice regular curb construction supports and gives sufficient protection to the edges of pavements. Reinforcing steel and steel fabric have often been used in order to minimize transverse cracking, and in an attempt to insure maximum service from the pavement. Cracking may be reduced by the use of steel, but recent experience indicates that it is better to expend all available funds for extra thickness of concrete rather than for steel. Considering all elements, and the fact that the concrete is but part of a project which eventually calls for a future wearing surface, it is believed that there is no justification for the expense of reinforcing, for contraction joints, nor for so-called expansion mastie joints.

62. Successful Repair of Concrete.—Complete breaking down of a well constructed concrete pavement occurs only in isolated patches, generally confined to a few square feet each and seldom containing more than a few square yards. These deteriorated spots may be due to one or more of several causes. Good construction practice has reduced their occurrence to such a minimum, and so much success can be obtained in their repair, that it would be uneconomical to attempt to preclude these broken down spots either by increasing the thickness of the slab or by the introduction of reinforcing metal. The success of repair work can be shown by reference to the pavement illustrated in Fig. 29. This street has somewhat greater use than most residential local streets since a bus line, each vehicle of which has a capacity of 32 passengers, operates over it. The bus trips average 375 per day. As shown in the photograph more than 50 per cent of the pavement now consists of patches which were largely necessitated because of plumbers cuts made at various times and also two longitudinal utility cuts. The bituminous protection of cracks and joints about the patches, as is apparent, is unsightly; but, otherwise, the pavement is unobjectionable. Its riding

qualities are not appreciably different from those of a newly constructed pavement. Experience with properly constructed 6-in. pavements indicates that repairs can be made economically and an allowance of 2 cts. per square yard for annual repairs should suffice. The volume of traffic on residential local streets not being very large, concrete patches can be laid and barricaded during the curing period without causing much annoyance to persons using the street.

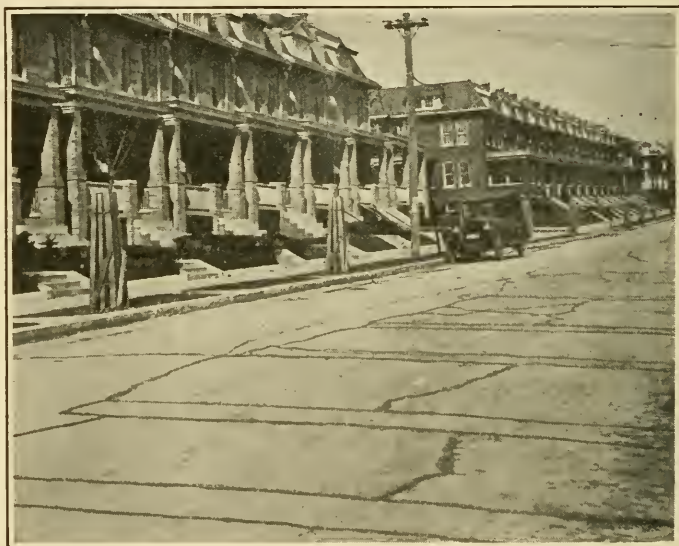


FIG. 29.—This picture illustrates that a concrete pavement can be successfully patched, leaving the roadway as smooth for travel as when first laid. The joints about the patches have been treated with a bituminous cement and sand.

63. Bituminous Top for Residential Local Streets.—The life of a concrete pavement on a residential Local Street can at the present time be only estimated. As has been heretofore brought out, it is wise to arrange for complete payment on the basis of a probable service of 20 years; and, in the original construction, to adopt grades that permit the addition of a new surface at some future time. Bituminous mixtures successfully compete with all others for this surfacing. They need be laid to a finished thickness of but $1\frac{1}{2}$ in. or slightly less; and, therefore, effect a large saving in materials as compared with other types. Also, in most cases, the bulk of these materials are available locally and

are relatively cheap. Other factors in favor of a bituminous top are the excellent results cheaply obtained in repair work and the ease with which, when the top is worn out, it may be stripped from the base and replaced with a new one. The bituminous surface should be tapered out to a thickness of an inch at the curb lines, and the curbs originally set so that a display of $\frac{1}{2}$ in. more than an average may be shown during the service of concrete alone; and of $\frac{1}{2}$ in. less than an average, after the bituminous surface is placed. Based on an estimate that a bituminous top can be laid for \$1 per square yard calling for an expenditure of 1.7 cts. per square yard for equated annual repairs (which figures are not far from average) and using the annuity table, with money at 4 per cent and an assumed service of 20 years, the annual cost for this top will be 10 cts. per square yard.

Naturally, other wearing courses than bituminous can be used for surfacing original one course concrete pavements; but they are more expensive. Being generally thicker, they require the use of more materials. Because of this excessive thickness it is difficult to allow for proper curb adjustment. More expense than is required for the relatively thin bituminous top is not justified for a residential Local Street.

64. Service from Bituminous Top.—The probable life, 20 years, for a bituminous top is not so much an estimate as in the case of one course concrete. Bituminous sheet surfaces have been in use in this country for close to a half century and it has been amply demonstrated that they do not need replacement even under fairly heavy and large volume traffic until, on the average, an age well past 20 years has been reached. Some communities have not gotten this result; but, as is also the case with other acceptable types of pavements, failures have been due either to faulty work of construction or to absence of maintenance and this latter cause is the more common of the two. The question of maintenance is one thing that has retarded the growth of bituminous pavements in small cities. It has been common practice to have contractors guarantee work for some short period, generally 5 years. This in itself is not good practice as has been explained under "Guarantee and Maintenance," Chap. III, and, moreover, if the pavement has been properly constructed, it is unnecessary since there should be practically no maintenance during the first 5 to 7 years. After the guaranty has expired and the time arrives that repairs are really needed, many small cities

find that no contractor is available to carry out the limited work required, the city does not have the facilities to do it, maintenance is neglected, and the pavement prematurely goes to pieces. Today there is no necessity for such conditions. Bituminous repair has been made a simple matter and equipment has been designed on a small scale so that it is feasible for even the smallest of cities to do their own maintenance work.

65. Lean Concrete Base on Residential Local Street.—For residential Local Streets if a bituminous surface is desired when a pavement is first laid, a lean mix is suitable for the concrete base. This procedure has not been recommended for general conditions because it usually involves a greater burden of expense upon the property owner than the plan outlined in the preceding paragraphs. While lean concrete uses considerably less cement than rich concrete the saving thereby cannot be expected to be equal to the cost of the materials in a bituminous top. Furthermore, the hauling costs alone for a bituminous top always amount to a considerable sum. When concrete is laid as a base, not as much time and labor is necessary to bring it to a finished surface as when the concrete constitutes a one course pavement. This saving is counterbalanced, however, by the relatively large plant and labor charges connected with bituminous surfaces.

For Local Streets there is no essential difference in the service rendered by the two-payment types. Many people, however, prefer bituminous sheet surfaces as having better appearance than portland cement concrete seamed with cracks outlined in black. Such preference should be favored only when property owners are willing to pay the excess cost entailed by adoption of the higher priced type.

66. Lean Concrete Base for Greater Traffic.—In the case of a street used to capacity every day, as for instance a Traffic Highway or Local Street in front of warehouses, a repair cannot be barricaded for a long period while the material used in patching cures. This precludes the adoption of one course concrete, as has been recommended for residential Local Streets. A two course construction is preferable: First, a base of sufficient stability to distribute the loads successfully to the sub-soil so that the pavement will remain true to line and cross-section under traffic; second, a wearing surface that (a) can be easily patched with a minimum inconvenience to traffic, (b) will have a long life so that traffic will be interfered with only at long intervals on account of

complete replacement, and (c) can be quickly rebuilt so that traffic will be kept from the pavement but a short time whenever replacement is necessary. During the early days of a street opened through new territory the preceding principles as to a separate wearing surface need not necessarily apply; even on a Traffic Highway, as has been previously mentioned (see "Development of Traffic Highways," Chap. IV), one course rich concrete may be used when there is not a great volume of traffic. The thickness in inches of this one course construction should be the same as for a lean concrete base under a wearing surface on a street of like character but fully developed. This question of thickness is discussed in later paragraphs.

In the days of John Macadam and Telford, stability was obtained in highway improvements by increasing the thickness of the roadway often to 18 in. or even more.

In the bottom courses large stones were used, each carefully set in place by hand. This substantial construction distributed the loads over the sub-soil so that the surfaces kept their shapes and local depressions did not appear. Just after the Civil War in this country many patented bituminous constructions were tried out. In these an attempt was made to obtain stability without great thickness by making a slab of concrete in which the aggregate was bound together with bituminous cement. Early in the last quarter of the past century hydraulic cement, first natural and later portland, began to displace bituminous cement in concrete slab construction; and, today, when a concrete highway base is spoken of, unless specifically qualified by use of the word bituminous, the assumption is that portland cement concrete is meant. In the great majority of cases, the requisite stability can be obtained at much less cost by using portland cement than by using bituminous cement. Whether macadam, telford, bituminous or concrete base construction should be adopted, provided they all give equal stability, depends largely upon their relative costs.

For bituminous wearing surfaces, concrete has one advantage over a bituminous base because of the ease with which the wearing surface may be repaired, and when worn out, stripped from the concrete base and replaced with new. Generally a bituminous top sticks to a bituminous base so that it is impracticable to separate them. The pavement being torn up in Fig. 30 was laid in 1873 and covered with a new surface in 1895. Its



FIG. 30.—Eight to twelve inches of bituminous pavement being removed because the worn out surface cannot be stripped from the base. The original pavement was laid in 1873 and was covered with a 3-in. surface in 1895.



FIG. 31.—This pavement was laid in 1895 and illustrates that a thin bituminous surface, if on a concrete base, can be readily stripped from the base and replaced with new.

removal is an expensive operation and requires mechanical means, as for instance a steam shovel. Though it is a pity that 8 to 12 in. of pavement is being removed there is no other satisfactory recourse. The surface cannot be stripped from the original pavement, and to place another on top would bring the pavement above the curb. As a contrast, Fig. 31 is shown. This pavement was constructed in 1895 and the removal of the surface today is a simple matter, requiring only crowbars and sledges. Of course, there is the surface heater method of resurfacing, by which the old surface, to a small depth only, is heated and removed, and a new surface, generally 1 in. in thickness, is laid. In considering this method it should be borne in mind that a wearing surface is no better than its total thickness of new material. If 1 in. is sufficient, more economy will be obtained by placing it on a concrete base from which it may be readily stripped, than by placing it on a bituminous base from which it may be removed only by applying a surface heater.

67. Concrete Base Repairs.—A one course concrete pavement, as has been brought out, is not suitable for a street used daily to its full traffic capacity, since concrete patches have to be barricaded for several days. A concrete base, protected by a wearing surface, should need no repairing because of deterioration, and therefore, only in the exceptional case of trenching, should patching be necessary.

A cut through a concrete base for utility purposes or plumbers' connections can be repaired without undue interference with traffic. First the trench should be carefully back-filled and given a temporary surfacing with old street material or cold bituminous patching material. Traffic will beat down the material in the trench; a few minutes attention each day will suffice to keep the crossing in a fairly smooth condition. After several weeks it will be found that settlement ceases, whereupon the trench can be dug out sufficiently to permit patching the concrete base. If the trench is a wide one the concrete patch should be given several inches more thickness than the surrounding base. Again a temporary surface is laid. Conservative practice would dictate barricading for at least 2 days, but if it is absolutely essential the patch may be immediately opened to traffic. Experience shows that the concrete even under such trying conditions, since it is supported underneath by the soil and along its edges by the old concrete base, and protected above by the temporary surfacing,

will give good results. A temporary surface is used for several weeks in order that the concrete patch under traffic may reach a final position of stability prior to placing the permanent surface.

68. Concrete Base Thickness.—Experience has shown that a lean concrete base should be not less than 6 in. in thickness. Six inches has proven to be very satisfactory and whether it should be 7 in. is more or less an open question. On some of our heaviest travelled streets of today the adoption of 7 in. appears to be justified. Looking into the future, with an undoubted increase in the numbers of fairly large trucks and busses on our streets, the more general adoption of 7 in. would seem to be

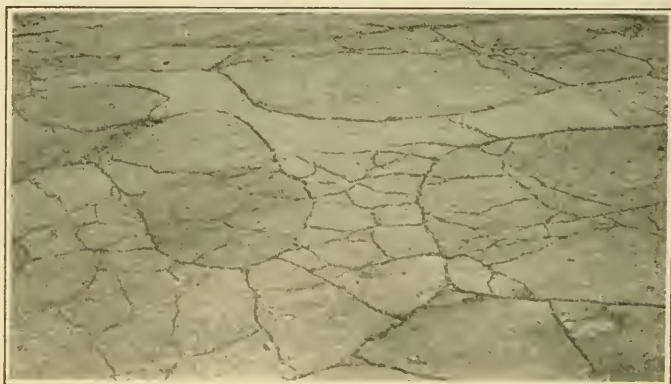


FIG. 32.—Eighty per cent of this entire pavement consists of patches accumulated at yearly intervals during the past 25 years. The continual bending of the asphalt surface on its flexible base, as loads pass over the pavement, breaks the asphalt into small lozenge-shaped pieces. Not only the original material breaks, but also patches of various ages and irrespective of the mixture used; fine sand (sheet asphalt), coarse sand (Topeka), or stone (asphaltic concrete).

warranted (“The Economy of Proper Design,” Chap. X, takes up the question of making the concrete richer rather than increasing its thickness). As with one course construction, excessively wet sub-soil should be cared for by an increase in thickness of the concrete slab, and for this purpose an increase of not more than 2 in. should be sufficient.

69. Impact and Rigidity.—Before leaving the subject of bases, it is well to say a word concerning some recent experimental impact tests of different types of pavement which by some have been held to indicate that because concrete is rigid it cannot give as good service as a base for a pavement as some other constructions of a more flexible nature. Many years of actual service

show that the stability necessary for a successful pavement may be obtained by using various constructions; a strong Telford foundation, a deep, well cemented bituminous base, or concrete. That type should be chosen that will give the requisite stability at least cost. Pavements are in existence with concrete bases of all ages up to and beyond 40 years. Some with rough and worn wearing surfaces have been in use more than 30 years, and still carry large volumes of traffic, including a fair proportion of 7-ton trucks, apparently without in the least affecting the efficiency of the concrete base. In view of the long and favorable practical experience with concrete bases, deductions from theory and short time tests as to the effect of load impact upon the probable life of this particular type of pavement should be accepted with caution. A bituminous surface on a flexible base may successfully withstand impact tests; but in interpreting the results of such tests it should be borne in mind that the experience of actual service on the street shows that breaking into small lozenge-shaped patches, as illustrated in Fig. 32, is typical of bituminous surfaces laid on flexible bases. In studying pavements of this nature a non-rigid base is not to be confused with a failing sub-base which usually results in complete destruction of the roadway.

70. Bituminous Top for Heavily Travelled Old Roadway.—Prior to discussing the various wearing surfaces that may be laid on a specially prepared base course, a word is necessary as to the conservation of the waterbound and bituminous macadam roadways that are found more or less in all cities on important and heavily travelled streets. Surface treatment as was recommended for old roadways on residential Local Streets does not give satisfactory and economical service under heavy traffic. On the other hand it would be improvident to cover up the hazards that may exist in an old roadway with a very expensive wearing surface. Further, whether or not any surface can be satisfactorily added to an old roadway depends largely on the cross-section and general shape of the latter. If large adjustments at the curbs, gutters, manholes, etc. are necessary it may be better to construct an entirely new pavement and this is true especially if it is necessary to cut off some of the old roadway or destroy the bond of the material, for this weakens the old construction to such an extent as to make it a very poor base for a wearing surface.

If it is decided that a wearing surface is justified, a bituminous mixture between 1 and 1½ in. in thickness will generally be found

most satisfactory. It does not call for a great amount of new material and is economical construction. Depressions can be filled with what is commonly known as a binder mixture. No attempt should be made to obtain ideal cross-sections and longitudinal grades. The aim in carrying out the surfacing of an old roadway is to get every cent's worth of value from it. If this can be done without interfering with satisfactory drainage, and at the same time give a fair riding surface, too much must not be expected in the way of pretty cross-sections and smooth straight



FIG. 33.—Placing of a 1-in. bituminous top on a macadam roadway that was originally constructed in 1917 and maintained since that time at an average cost of 25 cts. a square yard per year.

longitudinal lines. Under some conditions a bituminous surface constructed by the penetration method may compete with the "mixed" method just mentioned. One drawback is that it can hardly be laid in as thin a layer; therefore, more material is required and more adjustment of the old roadway.

In Fig. 33 is illustrated the placing of an asphalt top on a macadam roadway which was originally constructed in 1917 and maintained since that time by bituminous surface treatments and cold patching at an average cost of 25 cts. per square yard per year. Screed boards but one inch in thickness are used as guides for the rakers. The contract price for this surface, which, after

TABLE II.—COMPARISON OF MATERIALS IN THREE TYPES OF SURFACES

Materials	Material weight and cost per square yard		
	1-in. bituminous mixture	3-in. penetration surface	3-in. reinforced concrete
Sand.....	@ \$ 0.80 per ton		115 lb. = \$0.046
Gravel.....	@ 1.20 per ton		165 lb. = 0.099
Dust.....	@ 5.00 per ton		
2½-in. stone.....	@ 2.88 per ton	230 lb. = \$0.331	
1-in. stone.....	@ 2.88 per ton	40 lb. = 0.058	
Screenings.....	@ 1.08 per ton	30 lb. = 0.016	
Bituminous material.....	@ 15.00 per ton	23 lb. = 0.173	
Portland cement.....	@ 12.00 per ton		52 lb. = 0.39
Reinforcing.....	@ 0.06 per lb.		4 lb. = 0.24
Water.....			40 lb.
	110 lb. = \$0.157	323 lb. = \$0.58	376 lb. = \$0.78

rolling, is not quite 1 in. in thickness, was 65 cts. per square yard. Its probable life can, of course, be only estimated and likewise its yearly maintenance. Its life is estimated at 10 years with a maintenance cost of 3 cts. per square yard per year for that period.

In drawing up the project for this roadway surfacing two other types were considered, the materials necessary for the construction of which are set forth in Table II.

The thin bituminous top costs very little for materials and, there being relatively such small amounts to handle, it is also economical in labor. Transportation costs also are a minimum. For the roadway illustrated the haul was long and, therefore, transportation was considerable of an item; and yet, for the other two types, hauling would have cost about three times as much.

71. Bituminous Top for Old Stone-block.—The granite block pavement, the covering of which is illustrated in Fig. 34 was laid in 1871. Its total yardage is 15,000 and the cost for the improvement averaged 70 cts. per square yard. One-inch screed boards were used 3 ft. from the curbs. This leaves a granite block gutter as shown in Fig. 35, in order to save expense, since the roadway is 40 ft. wide and motors use the gutters only for parking purposes. Screed boards were not used in the center of the roadway, but instead, in advance of the raking, spots along the center line were chosen and built up with small patches of material so as to give a fairly uniform center-line grade. Deep depressions where a depth of more than $1\frac{1}{2}$ in. of material was required were partially filled and tamped with a cushion layer using the same material as in the rest of the roadway.

While in the case of this old stone-block pavement the same principles apply relative to the construction of the surface as for old macadam roadways the necessity of the work is different. In the case of the macadam an improved surface was demanded in order to eliminate excessive repairs. On the stone-block pavement no money had been spent for maintenance for many years but its surface was rough and travel over it was slow and uncomfortable. Traffic counts showed but 330 vehicles from 6 a.m. to 6 p.m. though the street occupies an important position in the city's highway plan. Improvement was called for from the standpoint of traffic alone. The daily average for the week following completion of the surfacing was 1,850 vehicles. Passenger cars multiplied in number by eight and trucks by five.



FIG. 34.—A thin bituminous cover for an old granite block roadway. The screed patches are "teed in" on the high spots of the granite block, using a minimum thickness to give a fairly uniform center line.



FIG. 35.—One-inch screed boards used along the edges of the work left 3-ft. gutters composed of the original surface.

72. Choice of Wearing Surface.—If a decision has been made that a new pavement is necessary, a choice from among the various types of wearing surfaces suited for city use is generally determined by (a) original cost, and (b) maintenance cost. The first depends largely upon the local supply of materials. The latter upon local soil and climatic conditions and also largely upon the training of the local organization taking care of pavements. It is for these reasons that there is no one standard surface; but instead, one municipality may be known as a wood-block city, another as a brick city, a third as a bituminous city, and a fourth as a stone-block city. Without an intimate knowledge of the care that has been expended in maintaining them no worth while comparison can be made of various types. Failure in the timely replacement of a single bad brick in a pavement means that traffic ruins a dozen surrounding bricks. The life of an almost worn-out bituminous surface may be prolonged many years by continuous maintenance; but neglect it for several months and it has gone forever.

Making a choice of pavement type based on information from other cities is further made difficult by the fact that records do not show whether or not pavements have rendered adequate service. It may be that pavements are being maintained for 2 cts. per square yard per year, but are results obtained satisfactory from the motor vehicle operator's standpoint? Increasing the maintenance expenditures by 50 per cent might save many times the amount involved through increased efficiency of motor vehicle operation. Again, the matter of obtaining reliable information from records is complicated by the fact that so many different qualities of pavements have been constructed under the general terms, brick, bituminous and wood and stone-block. Under each heading there have been many examples of worthless construction but records do not show the details thereof.

In the future a firmer status of comparison will be established because much has been done lately to standardize practice in each of the different classes of surfaces. There still remains, however, practically untouched, the problem of standardizing the analysis of cost and service rendered. Until such time as this is accomplished the service that can be rendered by bituminous, brick and wood block must be accepted as approximately equal. While the probable life of these surfaces is well beyond 20 years, that period however should be adopted for the amortization term

in the case of bond issues. Small stone-block, roughly cubical in shape, commonly known as "Durax," should also be placed in this same class. Choice from among the four types in this class, based upon an assumption of equal life and equal maintenance, depends upon original cost. If experience proves that one type

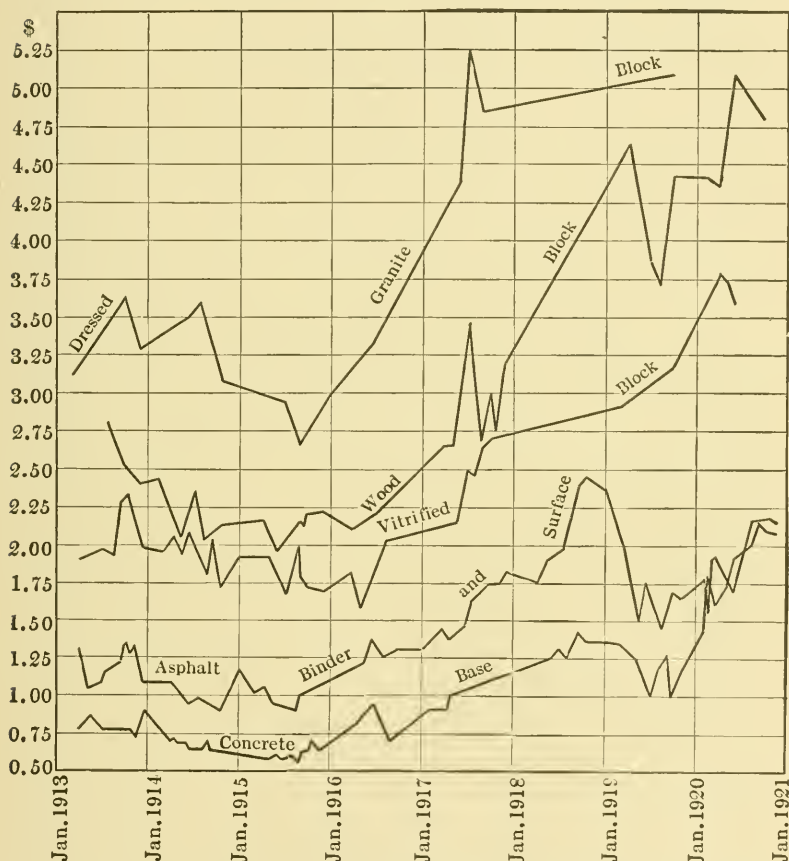


FIG. 36.—A comparison of low bids received in Philadelphia for concrete base, asphalt surface with binder, vitrified brick surface, wood block surface, and granite block surface.

gives longer service than another then a comparison should be made upon the basis of "Annual Cost of New Pavement" as previously outlined. While the details of construction and maintenance costs will be taken up later in connection with descriptions of the construction of each type of surface, Fig. 36

suggests how data bearing on his own local conditions should be kept before the engineer at all times. Not only should the low bid be plotted but also the average of all bids received on any one letting, also the engineer's estimate; and any great discrepancies in these three sets of figures should be explained.

It must be realized that the specific data in Fig. 36, pertain only to Philadelphia, and also that any deductions from them without a thorough understanding of the local conditions may be misleading. However, the information in the figure relative to granite block shows what is generally true; that a surface of large stone-block, usually having a depth of 5 in. and carefully cut to size by hand, costs much more than any other type. The use of these blocks, on a concrete foundation, with a bituminous filler, giving a fine riding, smooth surface is a development of recent years. It meets a special and restricted field—one where the requirements of traffic and business are above all of first importance. The best pavement obtainable is desired irrespective of first cost. The construction must be smooth, it must be longer lived than any other, and during its life must require less repairs. In other words, traffic, and business along the street, must suffer a minimum of inconvenience on account of surface maintenance and replacement.

Prior to leaving the question of choice of wearing surface, one point should be emphasized: The concrete base should be considered a permanent installation. Having once used a 2-in. wearing surface it is usually impracticable to substitute a thicker one. On a car-track street or where sidewalks and curbs fix elevations within very narrow limits, the substitution of even a 3-in. surface would present difficulties, and one with a 5 or 6-in. depth could be used only by tearing out all the old base and replacing it with new concrete.

73. Traffic Loads.—In state highway departments there are still some differences of opinion whether trucks as large as $7\frac{1}{2}$ tons, should be permitted on the state roads; also whether the largest trucks authorized should be allowed indiscriminately on all types of roadways or whether maximum permissible truck weights should be fixed for each roadway, according to type. In cities there need be no indecision. Experience has shown that $7\frac{1}{2}$ -ton trucks can be carried safely on the pavement constructions recommended in this chapter, both on the heavily travelled streets of a city and on residential local streets.

It has been recommended that the widths of trucks with their loads be limited to $7\frac{1}{2}$ ft. This is in order that the maximum carrying capacity of highways may be developed. Likewise, in order to obtain this maximum capacity it would appear to be unwise to eliminate the $7\frac{1}{2}$ -ton truck, for its load would then be carried by more than one truck and more space would be occupied on the roadway. Furthermore, we are not certain as yet, granted that two types of trucks are equally well designed, that two small ones would not do more damage to the pavement than one large truck. Gross weight alone is not the all-important factor. Speed, unsprung weight, wheel loads, character of tires, tractive stress on the pavement; all these enter into the matter. From the highway standpoint no difficulty is had in cities on account of speed since police departments on the grounds of safety generally cut down speed to fairly low limits. Fortunately, those other matters that cause undue wear of a pavement likewise affect the motor vehicle itself. Today over-loading is not only being opposed by the truck manufacturer but the operator also is beginning to realize that it wears out his truck prematurely.

Similarly, the successful operator does not use tires worn down to the rim because he has found that it is to his advantage not to do so. State restrictions that have been put into effect usually limit wheel loads to 800 lb. per inch of tire width, a restriction that is also favored by truck manufacturers. In general this is good legislation, but it does not protect against the use of worn-out tires, nor does it consider the great difference that exists in different kinds of tires. Of two tires, each carrying 800 lb. per inch width, one may transmit to the pavement a pressure of less than 100 lb. per square inch of contact, while the other may transmit close to 150 lb. per square inch. However, in view of the present tendency toward conservative development on the part of truck manufacturers there appears to be no need other than as suggested herein for regulations restricting the size of trucks used in the course of ordinary business and work about a city. For special cases, as for instance the movement of a steam shovel or the transportation of a huge steel girder, special permits should be required.

74. Tractive Resistance.—There have been discussed those elements that are of importance in the selection of pavements. There remain for mention certain characteristics that perhaps at one time were important, but which, since the almost complete

motorization of traffic, have become of minor consideration. Tractive resistance varies but little on the various smooth surfaces suited to city use. The difference is so slight compared, for instance, to the effect due to grade, that it is of small moment.

75. Slipperiness.—Slipperiness is likewise of little or no decisive importance. Wood block, when wet and dirty is the most slippery of city pavements and is not looked upon with much favor for use on grades above 4 per cent; though with modern equipment under the conditions of today, pavements should be kept so clean as not to become slimy when wet. Furthermore, the steeper the grade, the easier cleanliness is maintained. Even a light rain serves to flush the surface. Stone-block at one time was considered a rough pavement. Today, if the large expenditure necessitated by the use of stone-block paving is justified, its installation so as to give a thoroughly smooth surface is also justified. The relative slipperiness of stone-block, brick, bituminous surfaces, and concrete, cannot be said to be a factor in the choice of pavement in the case of any grade less than 10 per cent.

Grades above 10 per cent may exist on local streets but only when there is no alternative. Drivers of vehicles of all kinds use these grades only when compelled to do so. The steeper grades are above 10 per cent the more undesirable they are, especially for animal drawn traffic. Above 12 per cent a descent with a heavily loaded animal-drawn vehicle is dangerous even for the best of drivers, irrespective of the type of pavement. As such grades are exceptional, on them comfortable and economical motor transportation may be regarded as of secondary consideration, and conditions making for safe travel are of first importance. Pavements for these streets may have rough surfaces but must, however, be durably constructed so as not to wash away with every rain. Concrete or rough stone-block may be used to meet these conditions.

Bituminous surfaces have for years suffered in the minds of many because of the slipperiness of the limestone natural rock asphalts early imported into this country. Figure 37 is a picture of a long 10 per cent grade paved with an artificial mixture sheet asphalt. The roadway is not appreciably more slippery than if one of the other smooth dustless types of pavement had been used. It is not the surface but the grade itself that prevents the general use of the street as a thoroughfare. Drivers

of animal-drawn delivery wagons and those of the city refuse collection service have no difficulty with their work on this hill; though, of course, they show more judgment than to make its descent with, for instance, 4 cu. yd. of ashes behind two horses.

Bituminous surfaces vary somewhat as to slipperiness, dependent upon the size and character of the aggregate used and also upon the character of the bituminous binding material. The least desirable of these surfaces from the standpoint of animal-drawn traffic are probably some of our old macadam roadways with high crowns that have been treated with poor bituminous materials that have dried out and become hard with age. From the standpoint of the motor vehicle even



FIG. 37.—Sheet asphalt on a long 10 per cent grade. Not objectionable on account of slipperiness, but objectionable because motor vehicles have to shift from high gear and because animals cannot haul a reasonably large load.

these hard surfaced old macadam roadways cause little or no apprehension since the balance of motor vehicles has been so perfected that skidding has been reduced to a minimum.

76. Cleanliness.—All city pavements with smooth, dustless, and impervious surfaces are easily kept in a clean sanitary condition and from this standpoint no one type seems better than another.

77. Noise of Passing Traffic.—Wood block, with sheet asphalt second in favor, is generally considered the quietest surface under animal-drawn traffic, and concrete, brick and stone-block are considered noisy. Under rubber-tired motor traffic there is little or no choice. There are city ordinances in existence that require wood block on streets fronting hospitals, schools, and

certain other buildings. Such ordinances are at times unreasonable. Instances are known where car-line cross-overs at street intersections completely over-shadowed all other traffic noises; and again, where the entire absence of animal-drawn traffic made a smooth stone-block surface just as acceptable as any other. In only most exceptional cases should other than traffic requirements and cost limitations be decisive in making a selection from among those pavements that are smooth, dustless and strong.

78. Paving Adjacent to Car Tracks.—A great deal of the criticism that is commonly directed against the poor condition of paving within track spaces could be prevented; in the first

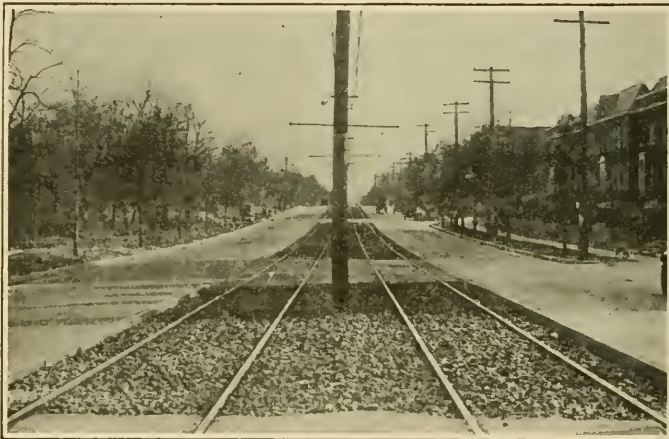


FIG. 38.—Preliminary development for a rapid transit street. Satisfactory provision for vehicular traffic on two one-way roadways and a minimum expenditure required for the track space. The 4-in. curb adjacent to the track was constructed on top of the edge of the pavement while the concrete of the latter was still green. This curb can easily be chipped off when it is desired to improve the track space and cover the present concrete with asphalt.

place by not paving the track space prematurely, and in the second place, whenever paving is done, by requiring satisfactory track construction. In the early days of the development of a rapid transit street car line, traffic is not of great volume. Generally, a T-rail of rather light section is used and, if the track space has to serve also as a roadway for motor vehicles, no type of surface can give first class results. The best way to improve such a street during its early development is to place the tracks within a center right of way in accordance

with the treatment shown in Fig. 38 (see also, "The Development of Rapid Transit Streets," Chap. IV). The roadway for motor vehicles should be of concrete placed on a depressed grade so that later it can serve as a base for one of the pavement surfaces previously mentioned in the present chapter. With a development as thus described, maintenance of track, tightening of joints and so on, can proceed with a minimum of inconvenience to motor traffic which is satisfactorily taken care of on the concrete side pavements.



FIG. 39.—For city use a rail with a groove or lip should be used. Especially is this true in the case of an asphalt pavement. Though the asphalt on the outside of the rail is in good condition, the car wheel flange grinds dirt under the asphalt and breaks it, as illustrated, along the inner edge.

When the volume of traffic increases to the point that paving the track space becomes necessary a rigid track construction should be insisted upon, together with a heavy stiff rail of the groove type. The rail should have at least a 7-in., 125-lb. section (9-in., 141-lb. sections are often used and with much satisfaction). Then, if the ties, in the case of an over-head trolley system, are imbedded in concrete, or the yoke properly set up,

in the case of an underground trolley system, no unreasonable amount of trouble should be had with any of the types of pave-

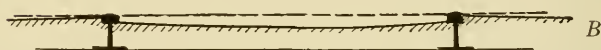
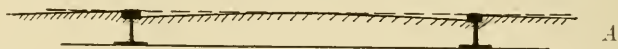


FIG. 40.—When bituminous paving must be used between T-rails the pavement should start from beneath the rail heads.



FIG. 41.—Asphalt paving adjacent to heavy grooved rail. No maintenance during 7 years.

ment surfaces that are appropriate for general city use. Furthermore, if rail joints can be so welded as to do away with the continuous adjustment ordinarily required with the usual bolted

joint, then conditions would be further improved. While this rigid track construction with its high first cost may be objectionable on one basis or another from the railway standpoint, it is essential, if satisfactory service is to be rendered those who use our streets, and more over, in the long run it will prove to be the most economical type of construction.

A T-rail from the railway operating standpoint is more economical than a groove rail. One-course concrete pavement

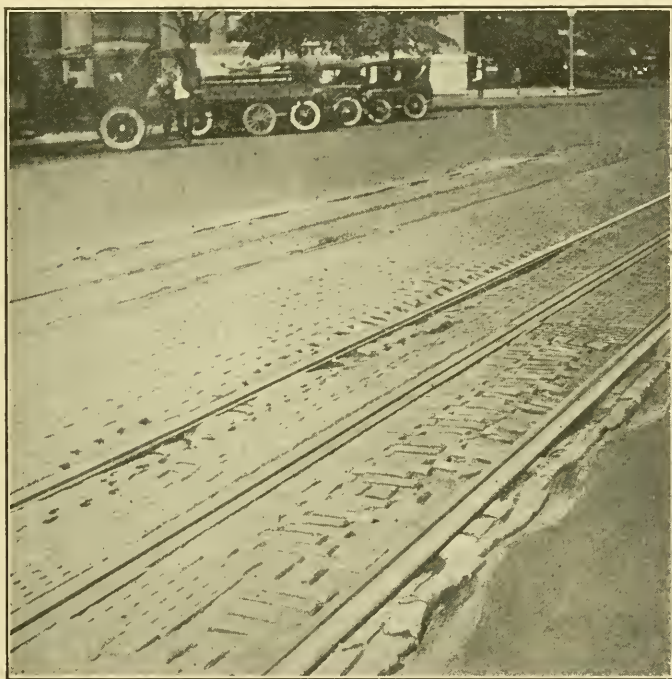


FIG. 42.—Pavement failure occurs, irrespective of the type of pavement or rail, if the track sub-structure is weak.

can be used adjacent to T-rail until such time as surfacing becomes necessary, then difficulty is had adjusting the surface to the grade of the tracks. T-rail for two-course pavements is always unsatisfactory. In the case of brick and block surfaces provision has to be made for the wheel flanges along the insides of the rails. If bituminous paving is used the wheel flanges grind dirt, ice or snow down under the pavement surface with results as shown in Fig. 39. When there is no alternative and

bituminous pavement must be used with T-rail, the surface should start from under the head of the rail as shown in Fig. 40*a*, or even be depressed between the rails as illustrated in Fig. 40*b*. With either design the wheel flanges cannot touch the pavement and in addition, with the depressed contour dirt and debris does not collect next to the rail. From a motor vehicle point of view these are objectionable designs.

It may be noticed that the pavement adjacent to the outside edge of the rail, shown in Fig. 39, is in good condition. Also, pavement may easily be maintained both along the inside and outside of heavy groove rail used with rigid track construction; which is illustrated by Fig. 41. This asphalt pavement is 7 years old and nothing has been spent to date on its maintenance. On the other hand, from Fig. 42, a photograph of a 9-year old track, it is seen that, irrespective of the pavement type, and also irrespective of the type of rail, poor results are obtained if the sub-structure of the track is weak. Of late years, continuous repairs have been required along the track illustrated. The block liners between the rail and the asphalt necessitate double maintenance work since both surfaces have to be repaired. These block liners should be removed and the asphalt laid abutting the rail.

79. Alley Pavements.—While naturally any of the roadway types of pavements that have been discussed, might also be used in alleys, it will be generally found that one course concrete 6 in. thick will fulfill all requirements and be more economical than any other type. The first cost is low and experience shows that the maintenance necessary for concrete alleys should be even less than for concrete on residential local streets.

80. Sidewalk Pavements.—Brick, flag stones, various paving blocks, and bituminous mixtures have all been used for sidewalks, and under exceptional conditions may still be adopted, but it is now generally acknowledged that a portland cement pavement is the most satisfactory of all for sidewalks. This type is usually floated to a smooth surface and marked into blocks about 3 ft. square.

81. One Course vs. Two Course.—For sidewalks it is important to point out those factors determining a choice between a two course design using a mortar topping, and a one course design. The former has been in common use for 30 years. The development of the latter in place of the two course design deserves

every encouragement. Though but limited experience has been had with one course construction for sidewalks, it has been sufficient to show that a surface, with an appearance equal in every respect to that of the mortar topped walk can be readily obtained; and further, that the one course construction is much the cheaper of the two. Experience with roadway pavements has long ago shown that one course construction is fundamentally correct.

With a mortar topping a walk has to be cut into small blocks, the joints extending clear through the base. Otherwise, having a different coefficient of expansion than the base and being laid in such a thin layer that it cannot take compression without

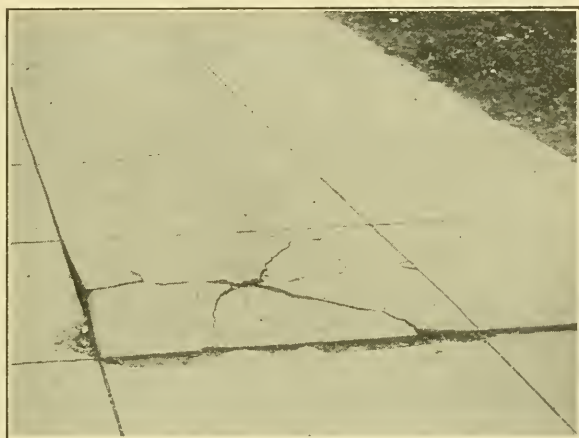


FIG. 43.—Pavement 1 year old. Mortar topping separated from the base. The breaks are due to the expansion localized within a block 3 ft. square.

buckling, the topping of mortar cracks, separates from the base and pushes up like the pitched roof of a house. Even with division into blocks, buckling of the topping as illustrated in Fig. 43, is not entirely prevented, and this notwithstanding most careful supervision during construction.

Detrimental results of compressive stresses in pavements due to the tendency of concrete to successively contract and expand are not directly proportional to the length of construction. In long continuous stretches of sidewalk the effect of longitudinal expansion is negligible, for the reason that the walk is held in position by its own weight and friction on the soil sub-base. Accordingly it is unnecessary to place soft mastic transverse joints in sidewalks. Often curb at street corners is pushed out of

line and usually the movement is ascribed to expansion in a long stretch of sidewalk, whereas in reality the long stretch sticks to its position, and as shown in Fig. 44 a 6-ft. length from the curb to the main walk is the cause of the trouble. The pushing out of curb by a short stretch of walk is again illustrated in Fig. 45. The remedy is to set the curb properly in concrete so that it will stay rigidly in place. Referring again to Fig. 43, it may be noted that if a slab is not held in place by its own weight, and it is not strong enough to resist buckling, it will move though the stresses are all localized in an area but 3 ft. square; and it is a fact that in such a case, soft mastic joints as ordinarily spaced could not have prevented the buckling.



FIG. 44.—The pavement edge, or joint, from *A* to *B* is straight and continuous, showing that the curb has been pushed out of place entirely because of the expansion in the 6-ft. length of walk between the line *AB* and the curb.

When longitudinal joints are cut through a pavement, if the pavement has not sufficient weight to hold itself in place, or if it is not confined by curb and buildings, the longitudinal joints will open, and this is a very objectionable feature and the most common defect of two course construction, as illustrated in Figs. 46 and 47. With one course design, there need be no longitudinal joints.

Not only does one course design do away with those objectionable features of two course construction which prevent the attainment of full value from concrete, but there is marked economy in construction cost in favor of the one course. With

a lean base and mortar topping, usually a total thickness of 5 in. is adopted. The cost of the materials in such a slab is gener-



FIG. 45.—Curb pushed out of place by 6-ft. leads lying between the curb and the sidewalk, while contrary to popular belief the curb opposite the trees remains true to line and grade.

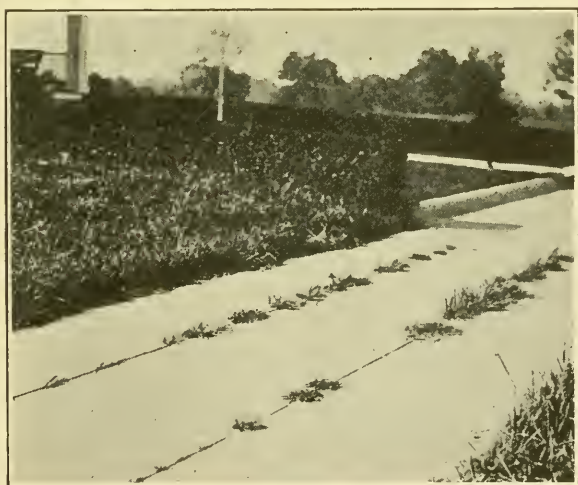


FIG. 46.—A two-course pavement 3 years old, illustrating the opening of longitudinal joints.

ally equal to that in a one course 5-in. slab of rich concrete; but for equivalent strength, the one course slab need be but 4 in. in thick-

ness, and therein lies the primary point of economy in favor of the one course walk. Another important saving lies in the elimination of the plant charges for a mortar mixer, and in the labor cost of operating it and handling the mortar. These savings will be described in detail in a later chapter.

For exceptionally poor sub-grade conditions, as discussed under the heading, "Sub-grade Drainage," Chap. VI, instead of using a foundation of cinders or other coarse material as is commonly done, the concrete thickness should be increased by 1 in.



FIG. 47.—A 20-year old walk showing not only the open longitudinal joint typical of two-course construction but also uneven settlement of the separate 3-ft. slabs. The projecting edge along the longitudinal joint has been chiseled down in order to protect pedestrians. Though the walk needs replacement, the concrete itself is as good as when newly laid.

82. Curb.—Prior to the days of concrete as a foundation for curb it was the practice to use curb with a depth of at least 20 in., with the hope that depth and weight would give stability. General experience, however, showed that the heavier and deeper the curb the more difficult it was to keep it true to line and grade. Since stones of such depth were expensive it was seldom that a dressed top width of more than 6 in. was adopted.

By using concrete as a foundation, as illustrated in Fig. 48, curb stones normally need be but 8 in. in depth (9 in., if a vertical curb face of more than 5 in. is shown), and accordingly more

top width may be afforded. A 6 by 20-in. curb has a cross-sectional area of 120 sq. in. while an 8 by 8-in. has but 64 sq. in. An 8 by 8-in. curb on concrete foundation not only gives more economy and service than a 6 by 20 in., but also on account of its wider top it lends more to the appearance of the street.

In addition to being cut from stone, curb may be molded of concrete, the general design of Fig. 48 being followed; and as with stone curb the foundation may be a lean mixture—the same as is used for roadway base. The curb proper should be the same mixture as adopted for one course pavement.

The material chosen for curb depends upon local conditions. Granite gives better service than any other material, but is often eliminated because of its cost; sandstone, limestone, bluestone or

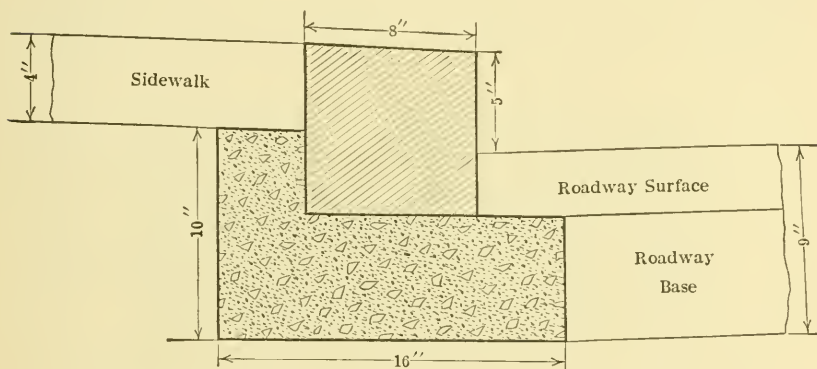


FIG. 48.—Eight by eight curb with concrete foundation.

other materials of local origin have often been substituted, and wearing qualities and appearance thereby generally sacrificed. Concrete is cheaper than granite but not so serviceable, nor so rich in appearance. It is usually cheaper than other stones and equal in wearing qualities to many of those that have been substituted for granite. Particularly in the case of circular curb, concrete is cheaper than cut stone because for the latter so much has to be cut away and wasted. Concrete curb is a good choice for residential Local Streets; but for its main streets every city should afford granite.

83. Gutters.—As stated under the heading “Gutters” in Chap. VI, no special gutter paving is necessary under normal conditions. Brick as commonly used in connection with asphalt is necessary only on flat grades, certainly on no grade above 3 per cent. It

is difficult to get a straight surface when rolling asphalt along the curb and therefore, on a flat surface there may be depressions large enough to hold objectionable puddles of water. This can be remedied by using brick gutters which in no case should be more than $1\frac{1}{2}$ brick wide; gutters one brick wide, and even an edging along the curb of brick laid end to end, thus giving a gutter the thickness of a brick, have been successfully used.

In suburban developments there are in existence many examples of concrete gutters constructed either integrally with the curb or separately, while the roadway pavement itself is of some cheaper construction. This choice has one drawback, in that when a new roadway pavement is laid, difficulty is generally had fitting it in with an old concrete gutter. Referring to the photograph accompanying the article "The Attitude of Abutting Property Owners" in the present chapter, assuming that money is not available for a complete roadway, certainly curb and gutter, at least, should be constructed at once, not only for the comfort of the residents and the appearance of the street but also for the protection of the trees. A good choice of gutter for this case would be an extra wide one constructed with old cobble or worn block salvaged from other paving jobs. These can be easily removed from the gutter when the full roadway pavement is authorized, and then are available for other make-shift work.

When a neighborhood builds up it may become desirable to install flat gutters along an old macadam pavement which is being conserved by bituminous surface treatments and for such a case old cobble or worn block are particularly adaptable since with them considerable adjustment may be worked out between the curb and the existing roadway, giving a result somewhat as shown in the photograph illustrating "Local Streets," Chap. IV.

CHAPTER VI

DETAILED STREET DESIGN

84. Intersection Plans.—In most cities there are a number of odd shaped street intersections with large expanses of surface not all required for traffic. These intersections can usually be improved by the use of islands, of which Fig. 49 is an example. Each intersection may require special treatment but there are two general principles to be followed: Traffic should be restricted to well-defined paths and vehicles should cross each other at right



FIG. 49.—An island of safety for pedestrians. It directs vehicles into well defined paths.

angles. If there is any doubt as to the practicability of a proposed island, a trial may be given with a temporary wooden platform before making the permanent installation.

Mushroom signals that show a colored light at night are useful when placed in certain classes of intersections, an example being shown in Fig. 50. Very often there is not sufficient room for the installation of islands at intersections where there is fairly heavy traffic and, in these cases, mushroom signals, particularly at night, serve to confine vehicles to proper tracks.

Previously it has been stated that a center line of islands in traffic highways is useful in that it keeps traffic to the right side of the roadway. Ordinarily it is sufficient, if the islands are located only at the intersections. They should be placed just back of the sidewalk lines of the cross streets as in this manner they serve their main purpose, at the same time affording safety spots for pedestrians.

85. A Circular Arrangement.—From a traffic standpoint an intersection consisting of more than two streets is objectionable, though from the standpoint of appearance very beautiful effects can be obtained. While in Chap. IV under "Block Divisions" a sub-division, eliminating such intersections is illustrated engi-



Fig. 50.—Mushroom signal with light showing through colored glass panels.

neers will find that there are many in existence and that others in addition will have to be accepted. Where there is sufficient area for the installation of a central circular park, and rotary traffic to the right can be established, conditions are greatly helped. If traffic can be isolated into separate streams as it moves about the circle conditions are again bettered. Fig. 51 is a photograph of Scott Circle, Washington, D. C., where three streets come together, all main thoroughfares, and one, Sixteenth Street, being of first importance. The long islands in the circular roadway divide it into an inner and an outer track, through Sixteenth Street traffic being given preferential treatment. Where the outside track vehicles cross the Sixteenth Street traffic at the ends of the islands, the crossings are made at right angles and accordingly just as easily as at the ordinary right-angle

intersection of two streets. A wide roadway is necessary to accommodate all the vehicles that at certain times concentrate at the circle. Prior to the construction of the islands confusion used to result due to the difficulty drivers had of knowing what course others were about to take. Matters were made worse by the large number of pedestrians that crossed the roadway during busy periods. At first, six small detached islands were tried. These were of some help to pedestrians but traffic did not separate into sufficiently well-defined streams. The islands as now

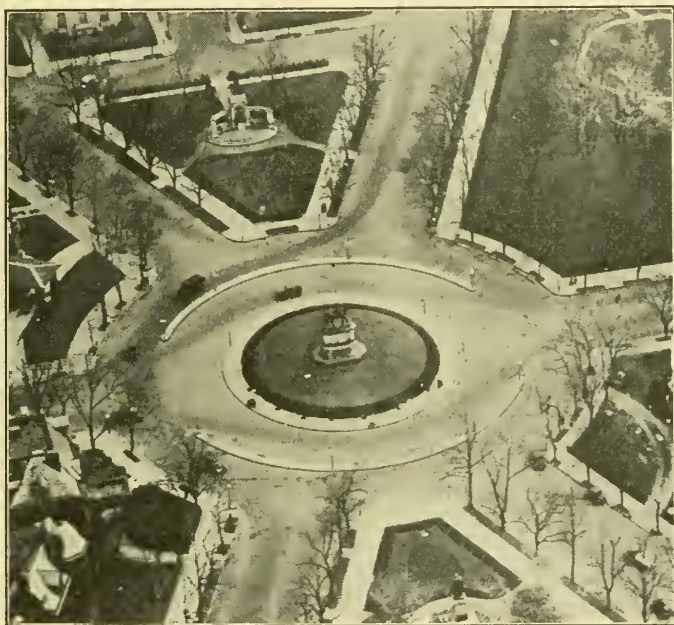


FIG. 51.—Concentric islands, about a circular park located at the intersection of three main thoroughfares.

(Photograph by Army Air Service)

installed permanently, are successful both from the standpoint of the pedestrian and the motorist. At the ends of the islands the roadway widths are each 30 ft. At the centers, the outside track is 31 and the inside 29 ft. This flattening of the arcs corrects an illusion and the two tracks appear of equal widths for their entire lengths. Installed in the roadway at the south end of the east island and the north end of the west, are mushroom signals, as protection for the lamp posts at these ends against careless drivers.

86. Another Multiple Intersection.—If there is any latitude in making a choice, a car line should not be placed on a street passing through a common intersection with two others. The location illustrated in Fig. 52, prior to the installation of the four islands, was very dangerous both for pedestrians and vehicle operators. In the busiest periods close to 2,000 vehicles pass in 1 hr. on the two streets, across the car tracks. The islands do not interfere, in the slightest degree, with traffic on the most important of the three streets, which is at right



FIG. 52.—A series of four straight platforms instead of a circular treatment, at the junction of three streets.

angles to the car line; nor with that on the car-line street; while traffic on the diagonal street is directed into well-defined lanes. The platforms are of a great benefit to pedestrians. In replacing the temporary wooden construction shown in the photograph, the platforms will be shortened so that persons may walk past their ends in going from sidewalk to sidewalk, and still be protected without stepping up and down over them.

87. Acute Intersection of Two Streets.—When two streets intersect at sharp angles as in Fig. 53a it is difficult to pass from one to the other, since vehicles in making a turn as indicated

on the figure move practically head on into two streams of vehicles. The crossing of lines of traffic should be at right angles.

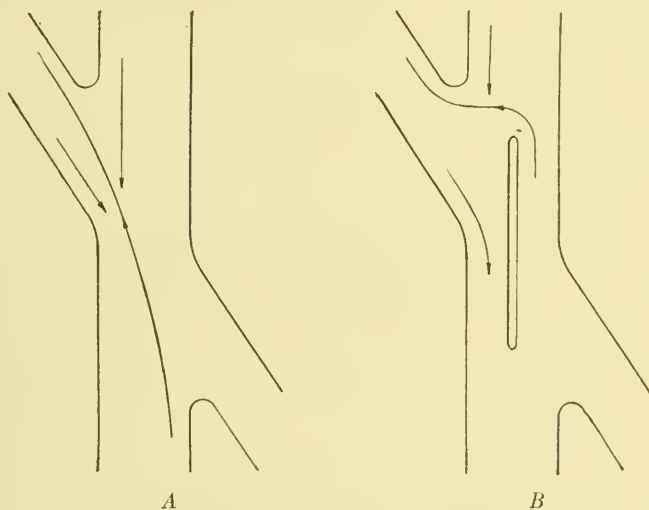


FIG. 53.

This result is obtained by the installation of an island such as is shown in Fig. 53b. In this particular case, traffic on the

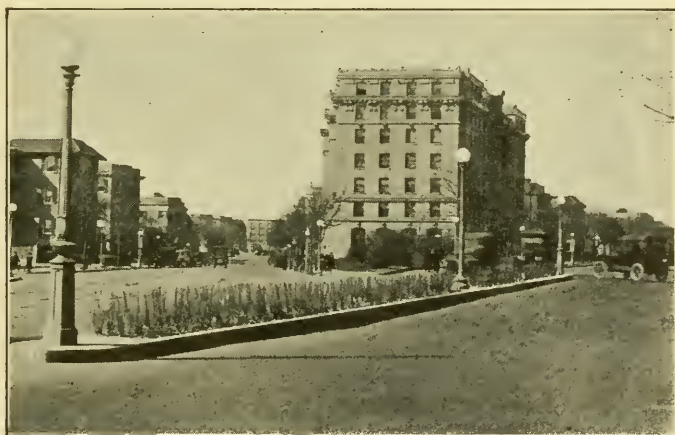


FIG. 54.—Long island in the center line of a traffic highway, at its acute intersection with a diagonal street.

wide important street is favored and does not have to deviate from the straight line, whereas that on the lesser street has

to turn about the ends of the island. The photograph, Fig. 54, illustrates an application of this scheme.

88. Circular Curb.—Years ago circular curb at street corners was habitually laid with a 6-ft. radius. This causes such a sharp turn for motors that it is objectionable under the large volume traffic of today. On Local Streets where a 6-ft. tree space and 6-ft. walk exist, a 10-ft. radius is feasible, gives a good appearance, and eases up the turn. On important streets with 20-ft. walks ordinarily a 15-ft., and in exceptional cases, even a longer radius should be used. Generally the curb radius, where sidewalks meet at a right angle, should not be greater than the width of the lesser walk plus the tree space. At the corners of an irregular intersection of streets it is well to use equal lengths of circular curb, though different radii may be thereby required. This gives a balanced appearance to the intersection.

89. Drainage and Minimum Street Grades.—In order to provide for the usual longitudinal drainage of roadways a mini-

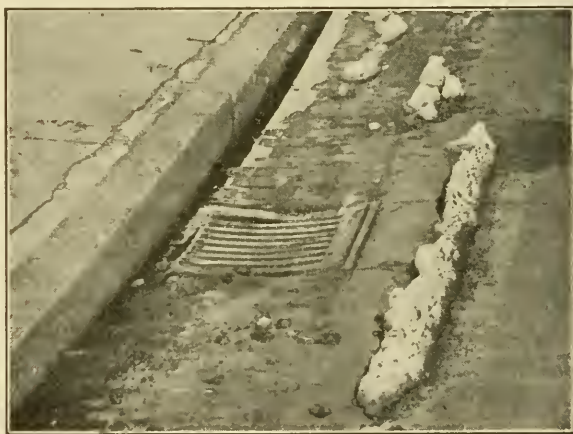


FIG. 55.—Gutter inlet to catch basin. Useful type where the drainage area is small.

mum grade is established. With the smooth high class and clean pavements that should be the rule in cities, this may be very small, but ordinarily not much less than 0.5 per cent. In case of necessity, however, roadways with no grade, that is level, can be successfully used. In these exceptional cases when level gutters are necessary, catch basins have to be installed at intervals no greater than 100 ft. and the gutter paving must be

maintained at all times true to line; otherwise, objectionable puddles of water will exist. Thus with bituminous pavements, for instance, brick gutters should be used since they can be laid and maintained to absolutely straight lines along the curbs more easily than bituminous gutters. Level gutters may be freely used in flat sections of country since the water to be carried away by each basin is that from a very restricted drainage area. This area extends half way to the next basin on either side and between the curb and the high point of the roadway crown. Fig. 55 is a picture of a gutter inlet in an unbroken stretch of level gutter 1,600 ft. long with basins at 90-ft. intervals. In flat country longitudinal drainage has often been obtained by placing a hip about the center of each block so that the roadways will drain toward the intersections. In such cases, even with very flat grades, the hips are noticeable and, if a street is long and straight with a hip between each intersection, a humpy appearance results that is objectionable. Some streets have been constructed with level roadway center lines and a saw-tooth effect along the gutters with basins at the gutter low points. This does not give as good results as when the gutters are level since the surface of the roadway is irregular, different depths of curb are shown, and the stoppage of an inlet causes a large pool of water.

90. Sub-grade Drainage.—It is well known that the bearing power of poor road bed soil may be reduced to a very small figure by increasing its water content; also that in the winter the water content is greater than at other seasons and that the seasonal variation is much greater than that due to intermittent rains. Generally, it is assumed that a dry clay sub-soil has a safe bearing value of 5 tons per square foot and a very wet clay less than 1 ton per square foot. Considerable moisture may be present in all soils without materially affecting their bearing capacities, but once the critical point of saturation is reached the bearing capacity slumps quickly to the minimum.

To keep moisture out of the sub-grade there are three methods in vogue, but more often than not, the adoption of any one of the three entails an expenditure without return. The most general method is ditching. On the sides of country roads open ditches are used and as far as they carry away surface water they are worth while; but in cities and in any case where transverse ditches are used, they are filled with porous material, broken stone,

cinders, etc., and unless water flows in these ditches it must be assumed that they do not serve to lower the water content of the soil. Likewise, when tile drains are installed, unless water flows through them the money expended therefor has been wasted.

Ditches and tile drains are useful only in the removal of run-off water from the soil and on its surface. The water, however, that generally causes trouble is that which is held in the sub-grade in spite of the presence of ditches and tile drains, and this water may, in the case of clay, exceed 50 per cent of the total volume of the soil.

The third method often adopted for improving sub-grade conditions is the placing of a layer of cinders, gravel, or broken stone under the pavement, and this practice is very common in sidewalk construction. Layers of coarse material, as ordinarily placed under pavements, do not serve as drains because habitually they discharge nowhere. They do not improve conditions in the underlying natural soil. To a small extent they lessen the heaving effect of frost action on the underside of pavements. A compact layer of coarse material acts to some extent as a slab, and as such adds to the strength of the pavement. The thicker and stronger a pavement the greater the area of distribution of pressures on the sub-soil and the smaller the pressure per square foot under load. Whatever benefit may be derived from a layer of coarse material, however, may be obtained at less cost by increasing the thickness of the regular pavement construction. Increasing the thickness also should be followed, rather than installing drains, in all cases of excessively wet spots from which the water cannot be made to flow by gravity.

91. Catch Basins.—Sewer traps and all those parts of catch basins beneath the street surface are usually designed and constructed by the Bureau of Sewers. That which particularly interests the Bureau of Highways are the locations of the basins and the design of those portions at the pavement elevation, and on these matters the two bureaus should work together.

There are innumerable styles of catch-basin inlets on the market and in use in various cities. One of the simplest and most satisfactory is the curb inlet shown in Fig. 56. When two gutters intersect with a low point at a corner, the inlet has to be located at the turn in the curb as shown in Fig. 57. This is not a particularly desirable location from some standpoints:



FIG. 56.—Wherever practicable, inlets should be located away from the turn in the curb.

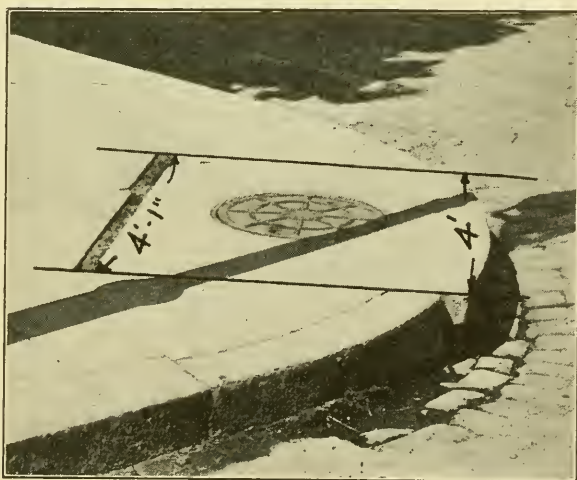


FIG. 57.—If this cover block had been made keystone shape with the greater dimension in the rear it would not have moved out from the sidewalk and curb.

Vehicles in making the turn rub the edge of the cover block to an unreasonable amount. This can be helped somewhat by cutting the edge with a longer radius than the rest of the turn. For instance, on a corner having curb of 12-ft. radius use a block cut with a 15-ft. radius. The turn is a poor location for a sewer wagon to stand while cleaning the basin. Pedestrians crossing the street intersection have to step over water flowing in the gutter toward the inlet. Whenever practicable, a location as shown in Fig. 56 should be chosen, as thereby the three objectionable features just mentioned are corrected.

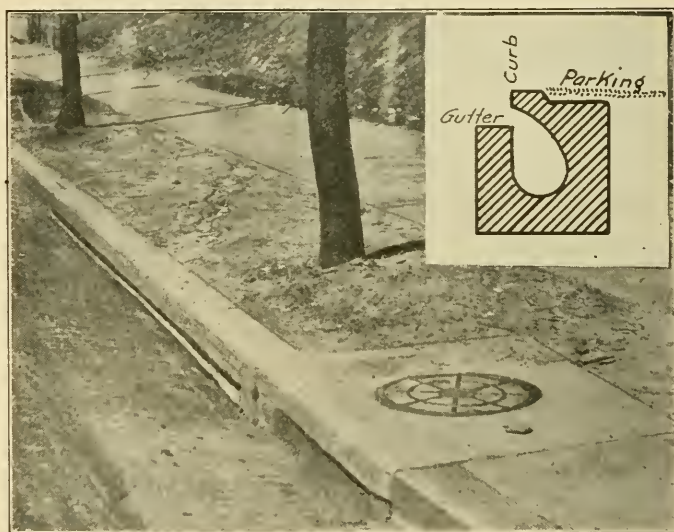


FIG. 58.—An elongated curb inlet on a steep grade. This construction is used in order to catch the water without the use of an objectionable obstruction in the gutter.

Cover blocks have a tendency to push out into the street as shown in Fig. 57. This is probably due to the action of freezing moisture in the joint at the back of the block. The displacement can be prevented by giving the blocks a keystone shape with a slight taper from the back toward the gutter, for instance, the width at the back edge may be 4 ft. 1 in. and at the gutter 4 ft. as shown on the photograph.

When a gutter inlet instead of a curb inlet is desired, that mentioned in the preceding article is a very acceptable style. When there is a necessity for catch basins at short intervals

this type probably gives a better appearance to the street than do curb inlets. An inlet covered with a grating should be used only when the drainage area is small. It cannot take the wash from a large area of street since in such cases a considerable amount of debris is collected and the grating clogged. At one time gratings were objectionable because horses caught the caulks of their shoes between the bars, but with the inlet close to the curb and traffic almost completely motorized this objection is of small moment today.

In Fig. 58, is shown a curb inlet used in a location where in time of storm the water in the gutter flows with such rapidity that most of the volume would flow by the usual small inlet. Sometimes an attempt is made to retard the passage of water by placing a hump in the gutter paving, but the results obtained are not nearly so satisfactory as when the inlet is lengthened. The cross-section insert in the photograph shows that the water flows from the gutter into a long barrel arrangement which at its lower end empties into the catch basin.

92. Manholes and Valve Boxes.—Other details of design, which while subject to the control of the sub-surface bureaus of

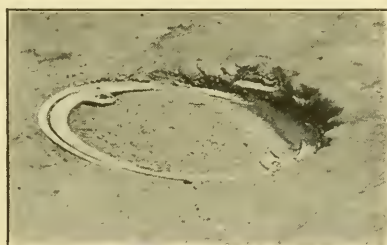


FIG. 59.—Manhole frame set on defective foundation.

the city, are of interest to the Bureau of Highways, have to do with the installation of manholes and valve boxes. Covers for the latter are usually small, 4 to 12 in. in diameter, and are of metal with "Gas," "Water," etc. appearing in raised letters. Manhole covers are larger and of many different types, corrugated, in order to give a foot hold, or else constructed so as to permit filling with the same material as used in the roadway pavement. Sometimes it is necessary to have perforated covers to permit the escape of gas, the accumulation of which might be dangerous.

A choice of cover can easily be made from the many satisfactory types on the market—a more difficult matter is the proper installation of the frames which hold the covers. The frames for manhole covers should be accurately set on rigid masonry so that tilting as illustrated in Fig. 59 cannot occur. Tilted and sunken valve-box frames are very common. These frames should be provided with flanges so as to rest on the concrete base of the pavement, and in addition the base should be increased in thickness immediately surrounding the frames.

93. Maximum Street Grades.—No definite rules can be given relative to maximum permissible grades. Judgment alone can gain the best results in fitting streets to the terrain. A few cities have examples of street grades of close to 20 per cent. Some rapid transit streets are known to have grades of more than 10 per cent, on which, of course, operation is costly. A street cannot serve satisfactorily as a Traffic Highway if it has grades as steep as 10 per cent. Even 6 to 8 per cent grades are undesirable but may be used for short lengths if lesser grades are impracticable. If they continue for more than one block, 6 to 8 per cent grades will slow up traffic markedly. Grades of from 4 to 6 per cent are proportionately less undesirable; while any grades up to 4 per cent may be used freely and without hesitancy for Traffic Highways. It is recognized that the steeper the grades the greater are motor vehicle operating costs, and even maintenance costs, because the more work done the more wear and tear on the vehicle. However, as long as drivers are able to take hills easily on high gear, or if stopped, pick up and shift into high speed no time is lost nor is the traffic capacity of the street lessened. These are points of real importance to the motor-vehicle operator as compared with small and intangible increases in fuel consumption and maintenance costs.

The grades that have to be adopted depend to a great extent on the nature of the terrain. The difference in elevation between the highest point of a roadway and the lowest point cannot be materially altered and this difference has much to do with determining intermediate grades. The succession of rises and falls between the extreme high and low points is subject to some adjustment however. On county and state roadways improvement is often obtained by corrections in alignment, but city streets are usually fixed as to location and in such cases their grades can be adjusted only by changes in the cuts and fills.

In this matter much foresight is necessary, for as with street widths, much money has been spent in correcting at a late date the too conservative policies of earlier design.

94. Cuts and Fills.—There are many important considerations that determine the grades of streets, and not infrequently make impracticable, adherence to the general rule that cuts should balance fills. In the establishment of grades on Rapid Transit Streets and Traffic Highways the needs of traffic are of first importance. On Local Streets the needs of abutting property are given greater consideration, though intersecting Traffic Highways or Rapid Transit Streets may definitely fix for short distances the grades on Local Streets.

Whether or not it is going to be feasible to develop an area often depends upon the grades established for the surrounding streets. Suppose a lot has to be graded for an average depth of 12 ft. at 45 cts. per cubic yard. This would place a charge of $1\frac{1}{2}$ times 45 or 20 cts. per square foot on the land. If this land has a low market value, perhaps even less than 20 cts. per square foot, it is evident that the establishment of street grades necessitating such grading would be ruinous to the property. On the other hand, if the land were of much greater value, the 20 cts. per square foot for grading might be of little or no significance. There is generally more latitude in establishing grades that require fills than those that require cuts. Often a large excess fill may be warranted because space for dumping ashes, earth from excavations, etc., is at a premium. Property owners at times are able to charge 10 cts. for each load dumped on their land.

95. Broken Grade Lines.—Long continuous grades are often made in order to develop important vistas, but ordinarily, grades may be broken at any or all street intersections as may best meet the requirements of traffic and abutting property. It is customary however not to break or change grades between street intersections. One exception is when hip construction for flat country is utilized. Sometimes permanent buildings constructed prior to the opening of a street may favor a broken grade line between intersections. It may be desirable at other times thus to break a grade in order to closely fit the terrain. These latter two cases are wholly in the interests of abutting property and should not be followed at the undue expense of other more general public interests. Seldom,

or never, should grades be broken so as to form depressions or drainage pockets. If catch basins in such positions become choked, water can escape only after flooding the streets.

96. Adverse Grades.—As a general principle grades should follow the trend of the terrain. For example, if a street lies along the drainage line of a valley its slope should be continuously descending, though the rates of grade may vary greatly in different sections. If in any section the direction is changed to ascending, an adverse grade is established. Adverse grades usually come into existence as follows: Property owners in the upper reaches desire their streets to cross a valley with the roadbeds close to the natural surface of the ground. This requires a minimum of fill in the valley but steep grades on the cross streets. Further down the valley may be an important cross street and steep grades are not permissible. The result is that the fill required for this street practically forms a dam across the valley.

In open country an adverse grade is of small matter (except as it affects the total rise and fall between two points) since the run off is slow and water may drain from the roadways through the fields. With city development the run off is rapid and water is collected in large volumes by the roadways. In times of storm, with correctly established grades, excess water may pass overburdened catch basins and eventually be taken care of. On the other hand, if an adverse grade is encountered, the accumulation of storm water at the low point will be found to increase year by year with expansion of the city. Unless an unreasonable expenditure is made in order to install sufficient catch basins and sewer capacity to carry away the water, it cannot escape except over the crest of the adverse grade. Flooding results not only of the street but also of the cellars of abutting property. The question of adverse grades is one of several necessitating coordination with the Sewer Division in the establishment of grades.

97. Vertical Curves.—There should be no abrupt change from one grade to another and, therefore at a break, the two tangents are connected by a vertical curve. A parabola may be used since it is the simplest curve to lay out and, in addition, gives a good transition from the tangents.

In Fig. 60, is a portion of a vertical parabola. By definition, the vertical line *PD* is parallel to the axis of the parabola and is called a diameter. The line joining the points of contact of the

$200 = 20 \times 10$. If the 2 per cent grade had been ascending in the same direction as the 8 per cent, it would have been considered negatively in taking the sum.

Suppose C to C' to be divided into 8 stations. Distances from the tangent $C8$ to the curve vary as the squares of the distances from C , while from the tangent $C8$ to the polar CC' , distances vary as the distances from C ; therefore, since 8 to $C' = 8$ to $8'$;

$$\begin{array}{ll} 1 \text{ to } e_1 = \frac{1}{8} \text{ of } 1 \text{ to } 1' & 2 \text{ to } e_2 = \frac{2}{8} \text{ of } 2 \text{ to } 2' \\ 3 \text{ to } e_3 = \frac{3}{8} \text{ of } 3 \text{ to } 3' & 5 \text{ to } e_5 = \frac{5}{8} \text{ of } 5 \text{ to } 5' \\ 6 \text{ to } e_6 = \frac{6}{8} \text{ of } 6 \text{ to } 6' & 7 \text{ to } e_7 = \frac{7}{8} \text{ of } 7 \text{ to } 7' \end{array}$$

It is sometimes troublesome to fit a street intersection to a vertical parabola. One side of the intersection, the curve may have the appearance of being humped, while on the other side flattened. The remedy is for the engineer to ease the curve by freehand in accordance with his best judgment. The elevations can be scaled from the drawing with accuracy equal to that obtained in the field work of constructing the pavement.

98. Cross-sections of Streets.—The cross-sections of streets should show elevation details of parkings, sidewalks, curbs, gutters and roadways. At street intersections these details may be rather complicated and cannot be easily explained by simple cross-section profiles alone. Contour plats facilitate an explanation.

99. Parkings.—The heights of parkings should be regulated so as to obtain reasonable uniformity within each block. One parking should not be cut to the grade of the sidewalk if the adjacent ones are high terraces. Neither should a high terrace and retaining wall be built when the other parkings in the block are low. The objectionable result of such practice is illustrated in Fig. 61.

100. Sidewalk Slopes.—Sidewalks need sufficient transverse grade toward the curb to shed water quickly. Concrete walks require the least slope of any and, for this type 2 per cent is enough. Other types, as for instance brick, require greater slopes, approximately 4 per cent being a maximum for ordinary conditions.

101. Curb Height and Slope.—The vertical face of curb that should show above the gutter varies with the width of roadway and should be a maximum of 0.55 ft. for the up-hill side of a very wide street (see article "Unsymmetrical Distribution of Crown" in this chapter), and a minimum of 0.37 ft. for a 24-ft. roadway. The top of curb should be dressed to a bevel. This may be greater

than the sidewalk slope, for instance, it may be 4 per cent for curb used with concrete walk.

102. Gutters.—Occasionally examples of barrel gutters are still found. For city use they are objectionable from several standpoints. They are difficult for pedestrians to cross and they prevent vehicles approaching close to the curb. In addition they are unsightly. A flat gutter, generally a simple continuation of the regular roadway pavement, is the most satisfactory



FIG. 61.—An unreasonably high terrace and retaining wall, obstructing the view from other houses in the block.

type. The gutter effect is obtained by increasing the rate of fall of the roadway from the center toward the curb. The steepest part of the cross-section being next to the curb, water flows in a stream not too wide for pedestrians to step across. It is a good plan, though not absolutely necessary, to confine the water next to the curb to a width of about 1 ft., with a slope toward the curb of 8 or 10 per cent for this width.

103. Roadway Crowns.—There are many rules for determining roadway crowns, one of the best known being Dare's formula, which has been in use many years and gives excellent results:

$$C = \frac{W(100 - 4L)}{6,300 + 50L^2} .$$

C = crown in inches; W = width of roadway in inches; L = longitudinal grade expressed as a percentage. The crown decreases as the longitudinal grade increases. Some formulas require more crown for asphalt surfaces than for other types, while other rules require the opposite. It is evident that more cross slope, in order to carry water quickly to the gutters, should be given a rough absorbent type of pavement than a smooth non-absorbent type. Steep cross slopes give a sidewise tilt to vehicles and make the effects of a slippery pavement felt more than slight slopes do. However, as has been previously brought out, the pavements suitable for city use are practically all in one class as far as smoothness is concerned and the question of cross slope may well be settled by the adoption of a single crown formula. One of simple application and a practicable mean of those in general use is as follows:

$$C = \frac{W}{10}(16 - L) .$$

For example, for a 50-ft. roadway and 4 per cent longitudinal grade, $C = \frac{50}{10}(16 - 4) = 60$, that is, 0.60 ft. since C = crown in $\frac{\text{feet}}{100}$; W = width of roadway in feet; L = longitudinal grade.

The foot, since all field work is carried out with that unit, is used rather than the inch.

The diagram, Fig. 62, gives the crown in accordance with this formula, from below 24 ft., the width of the roadway of a minimum local street to above 56 ft., the width of a traffic highway. For a wide rapid transit street the width of the car tracks is omitted in applying the formula. For example, a 72-ft. roadway with 16 ft. subtracted for car tracks would require the same crown as a 56-ft. traffic highway. The transverse slopes are laid off from the outside rails toward the gutters while the entire track space is a tangent connecting the slopes. If extra slope is given the gutters they should be considered separately from the

roadway. The crown then should be computed from the top of the gutter slope and the roadway width taken exclusive of the gutters.

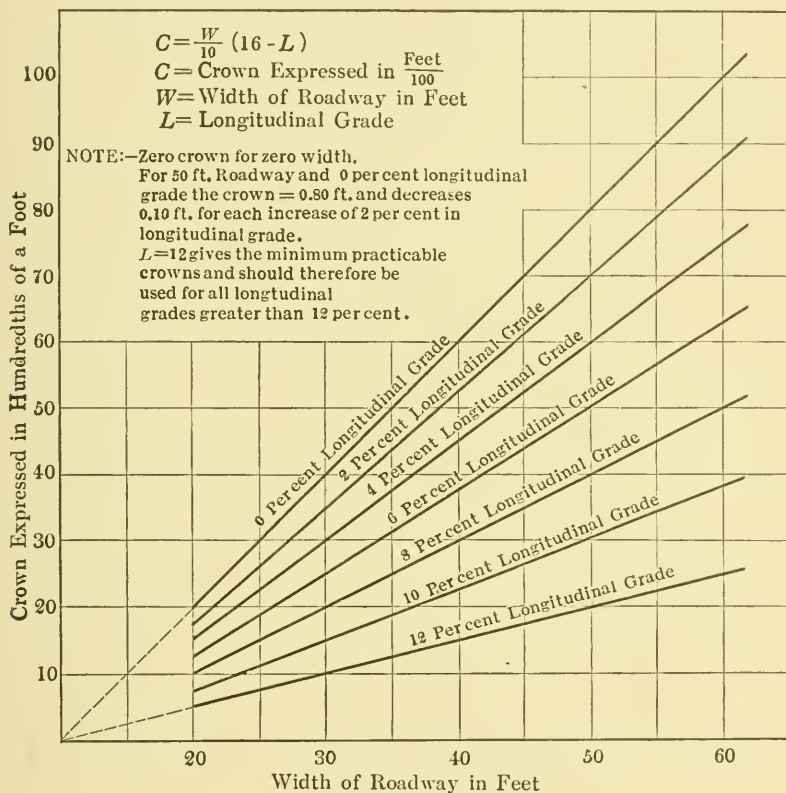


FIG. 62.—Crown diagram for the formula $C = \frac{W}{10} (16 - L)$.

104. Symmetrical Distribution of Crown.—When the gutter lines are at equal elevations, the high point of the crown is at the center of the roadway. Other points on the cross-section are often determined by the parabolic formula, which gives a drop of one-fourth of the total crown at a point half way between the center line and the curb. A better distribution is obtained if a drop of one-third is made at the half way points as shown at *H* and *H*, Fig. 63. The remaining two-thirds of the crown is then dropped between *H* and the curb. This plan gives a transverse

grade percentage from H to the curb double that from the center line to H .

$$T = \text{per cent grade } H \text{ to curb} = \frac{\frac{2}{3} \text{ crown}}{\frac{1}{4} \text{ width}} = \frac{8}{3} \frac{C}{W}$$

$$\frac{T}{2} = \text{per cent grade } \text{C} \text{ to } H = \frac{\frac{1}{3} \text{ crown}}{\frac{1}{4} \text{ width}} = \frac{4}{3} \frac{C}{W}$$

From the preceding equations it is seen that $C = \frac{3}{8} \frac{TW}{}$. Substituting this value for C in the crown formula,

$$C = \frac{W}{10} (16 - L),$$

the following is obtained:

$$T = 0.266 (16 - L)$$

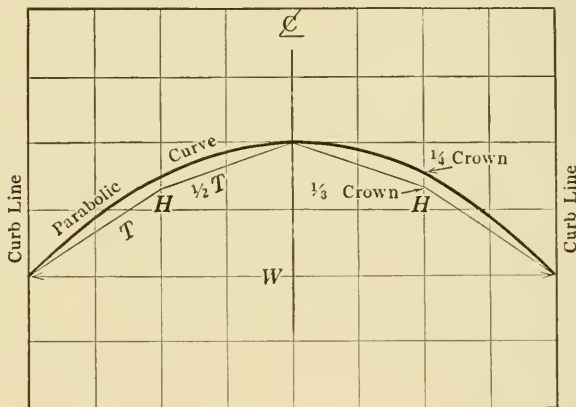


FIG. 63.—Comparison of parabolic distribution of crown with that by the formula $T = 0.266 (16 - L)$.

For example, with a 1 per cent longitudinal grade, $T = 0.266 \times 15 = 4$ per cent. The transverse grade varies only with L , the longitudinal grade. Thus there is but one value of T for all widths of roadways as long as L is constant. The relationship of T and L is shown by the diagram, Fig. 64.

Having drawn in the transverse grades the actual cross-section of the finished roadway may be shown by drawing arcs of circles through the center line and the gutters as illustrated in Fig. 65 T and $\frac{1}{2}T$ being chords of the arcs. For work in the field, if the roadway width is less than 40 ft., in addition to laying out the gutters, only those elevations at the center line and at the quarter

points, that is at H and H' , need be given. Workmen have no difficulty with crowns if grade pegs are at approximately 10-ft. intervals. If the roadway is wider than 40-ft., elevations may be scaled to the arc on the cross-section in order that intermediate grade pegs may be set.

In Figs. 63 and 65 the vertical scale is greatly exaggerated in order that it may be easily seen how the parabolic curve differs from the straight lines T and $\frac{1}{2}T$, and how closely the curves

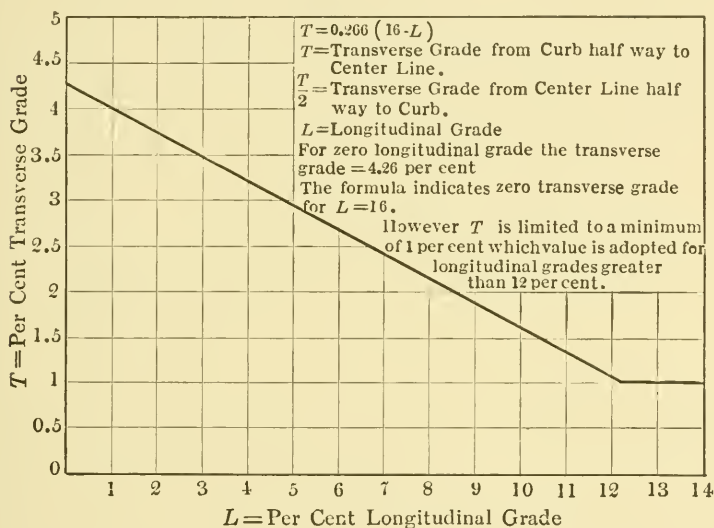


FIG. 64.—Transverse slope diagram for the formula, $T = 0.266 (16 - L)$.

based upon $T = 0.266 (16 - L)$ follow these lines. Compared to the parabolic curve, the cross-section Fig. 65, appears to give a sharp break at the center line which, in reality, however, is imperceptible in a roadway. While the departure from the parabolic curve is small, the T formula gives better crown distribution and great ease of application in actual practice.

It may be noted that the crown formula $C = \frac{W}{10} (16 - L)$ is of secondary importance, since the transverse slope formula is sufficient for laying out cross-sections, and in fact, for unsymmetrical roadways its use is the only satisfactory method.

105. Unsymmetrical Distribution of Crown.—An unsymmetrical distribution of crown is necessary when land abutting one side of a street is higher than that on the other. This occurs

whenever a street is built on the side of a slope. Cross streets cause the gutters at the intersections to be higher on the up-hill side than on the down-hill side. Between intersections, property on the up-hill side is above that on the lower side. Sidewalks and curbs are also higher on the up-hill side; and, unless the accompanying gutter is placed higher than that on the down-hill side of

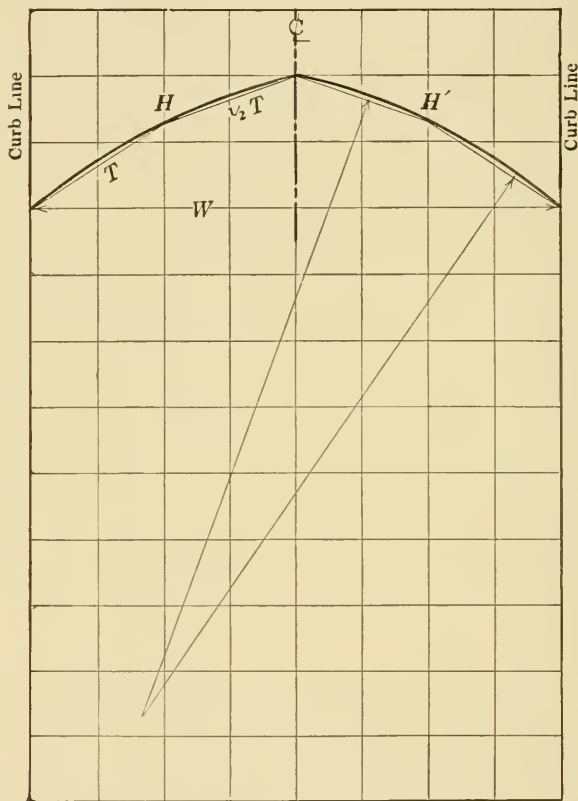


FIG. 65.—The pavement surface is represented by circular arcs drawn through the points established by the formula, $T = 0.266 (16 - L)$.

the street, a very unsatisfactory appearance results. Sometimes there is a mistaken idea that roadway cross-sections must be symmetrical, with gutters on the two sides of a street at equal elevations; and, in order to attain this, steep slopes have been given sidewalks on the up-hill side. Also, curb has been set with extra height, above the gutter, showing as much as a foot whereas 0.55 ft. should be a maximum even in most exceptional cases.

These expedients when made use of to a reasonable degree are helpful but they should not be applied to the extent of placing the up-hill gutter at the same elevation as the down-hill one. A difference in elevation is necessary in order to give a side slope street a good appearance. An unsymmetrical crown can be designed and constructed in the field just as easily as a symmetrical one.

The formula, $T = 0.266 (16 - L)$ for the transverse grade, which has already been explained, is also used for unsymmetrical roadways; and, therefore, its value can be taken from the diagram, Fig. 64. The high point of the crown, however, is not in the center of the roadway. The cross-section may be laid out as in the following example. In Fig. 66 the elevation of the low gutter =

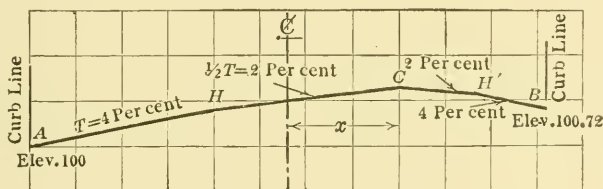


FIG. 66.—Unsymmetrical distribution of crown.

100 ft., that of the high gutter 100.72. The roadway is assumed to be on a 1 per cent longitudinal grade; and, therefore, from the diagram, Fig. 64, $T = 4$ per cent. Three per cent is the mean slope from A to C and is the same as that from C to B; but the rise A to C is 0.72 greater than the fall C to B. Accordingly, the distance A to C must be greater than C to B by a number of feet equal to 72 divided by the mean slope, or $72 \div \frac{3}{4} = 24$ ft. Suppose the roadway width to be 56 ft., then; $2CB + 24$ ft. = 56 ft. $CB = 16$ ft. and $AC = 40$ ft. Furthermore, it should be noted that the distance from the center line to C equals 12 ft. = $72 \div 6$ or the difference in gutter elevations divided by $T + \frac{1}{2}T$. Elevations at the points H, C, and H' are easily computed, for example: $H = 100 + 4$ per cent of 20 = 100.80 ft., $C = 101.20$, $H' = 101.04$.

The increase in elevation to be given the high gutter above that of the low gutter is a matter of judgment and should be at least sufficient to give smooth connections at the street intersections. There is a limit to the extra elevation that may be given the high gutter. In Fig. 66, as the gutter at B is raised C approaches B and coincides therewith when H is at the center

line of the roadway. In such case the cross-section is as in Fig. 67, and the limit of extra elevation of the high gutter equals twice the crown given by the formula $C = \frac{W}{10}(16 - L)$.

To sum up; for an unsymmetrical distribution of crown, where E = difference in elevation, stated in hundredths of a foot, between the gutters, and X = the distance, in feet from the center line of the roadway to the high point of the crown.

$$T = 0.266 (16 - L)$$

$$\frac{E}{1.5T} = X$$

For example, if $E = 0.72$ ft. and $T = 4$ per cent, $X = 7\frac{2}{6} = 12$ ft.

Maximum Value for $E = 2C$.

$$\text{Where } C = \frac{W}{10}(16 - L).$$

106. Car Track Sections.—As has been previously stated, car tracks on symmetrical crowns are laid so that the rails are at equal elevations. A common practice has been to crown the

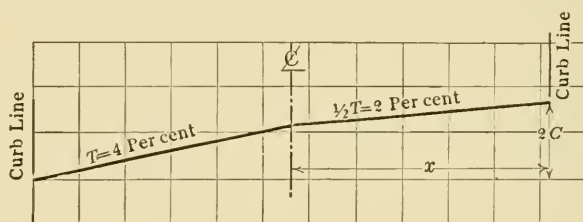


FIG. 67.—Maximum extra elevation for the high gutter.

pavement between the rails of each track and also in the dummy which practice gives a series of bumps to any motor vehicle crossing the car line. These bumps are particularly objectionable at street intersections. Any benefit derived from their existence is insignificant in comparison to their objectionable features; and, accordingly, the track space should be flat from outside rail to outside rail.

Objections are often raised against placing car tracks on an unsymmetrical crown. At times, under conditions as shown in Fig. 66, the tracks are placed off the center line of the roadway in order that the rails may be laid at equal elevations. When the roadway is shaped as in Fig. 67, sometimes each separate track is placed with its rails at equal elevations and the entire slope of the track space concentrated in the dummy. This practice gives

to the street an objectionable cross-section. A transverse slope across tracks of as much as 2 per cent entails no hardship, from a transit operating standpoint, that is not recompensed by the benefits to the general public through having a correct cross-section for the street.

107. Contour Diagrams.—An understanding of roadway shapes is helped by making contour diagrams as in Fig. 68.

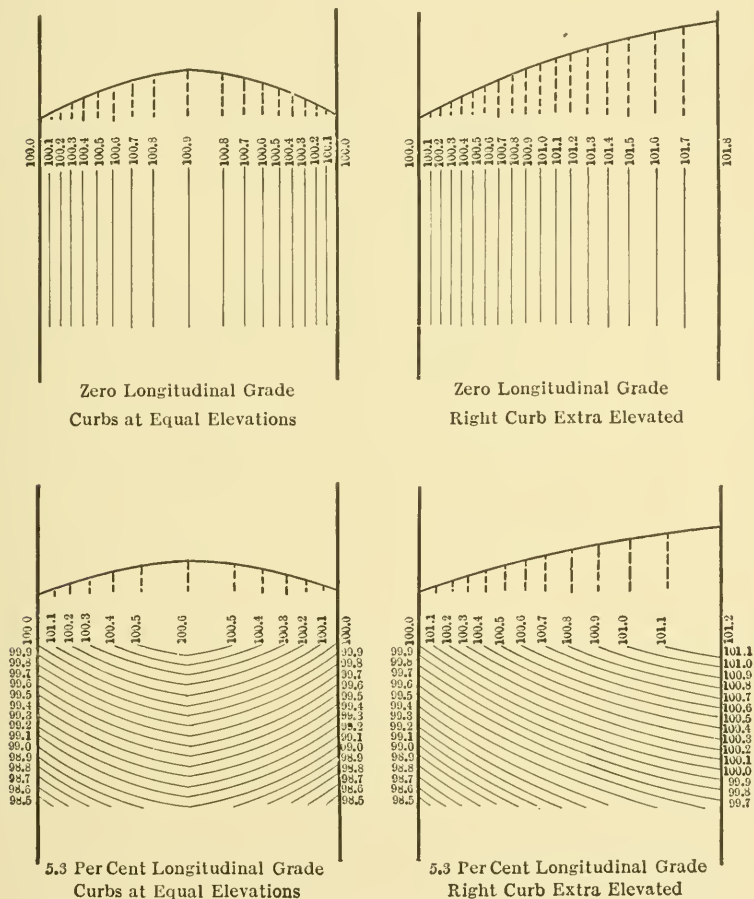


FIG. 68.—The four elementary roadway shapes, represented by contours.

Four cases are shown; two with curbs at equal elevations, one case having a longitudinal grade, the other none; and the remaining two with curbs at unequal elevations, one case with and the other without longitudinal grade. Surface drainage flows to the

gutters along lines normal to the contours, and the slopes along these lines are combinations of the longitudinal and transverse grades. This is the reason that the transverse grade should decrease as the longitudinal grade increases, otherwise unreasonably steep slopes toward the gutter are introduced. A roadway on a longitudinal grade corresponds to a topographical ridge and the contours are always convex down-hill. Contours convex up-hill outline valleys and are met with only at roadway intersections. Even there, except in the vicinity of catch basins, every effort should be made to so merge the roadway surfaces as to introduce as few contours, convex up-hill, as possible.

After a little experience intersections can be mapped out quickly and successfully by means of contours. One inch equals 10 ft. is a good scale for an intersection plan since then an engineer's scale may be used in laying off contour intervals along the gutter and other grade lines. For instance, with a 6 per cent slope and 0.1-ft. vertical interval, the sixty-parts-to-the-inch scale reads to hundredths of a foot in elevation, and a space of ten-sixtieths on the scale represents the contour spacing. Similarly a space of twenty-fiftieths on the fifty-parts-to-the-inch scale represents the contour spacing for a vertical interval of 0.1 ft. on a 2.5 per cent slope; and the engineer's scale in like manner has a wide application. Scales for slopes, for which the engineer's scale cannot be used, can be provided by using cross-section paper with 10 divisions to the inch. The spacing of the horizontal lines on the paper may be assumed to be 0.1 ft. For example, if a 2.3 per cent. slope is drawn, the abscissas of the points of intersection of this slope with the horizontal lines give the contour spacing.

108. Grades at Street Intersections.—Working out the grades for street intersections requires judgment, the exercise of which may be somewhat elastic as regards details. Certain general rules can be stated, however, and these can best be explained by examples. After determining the grades, a contour map of the intersection serves as a check since from it the engineer can picture the appearance of the completed pavement.

In Fig. 69*a*, a 40-ft. roadway, on a 4 per cent grade, is intersected by a 30-ft. roadway on a 1 per cent grade. These grades having been originally established only along the center lines of the roadways are increased slightly, where they traverse the blocks between intersections, by any flattening that may be

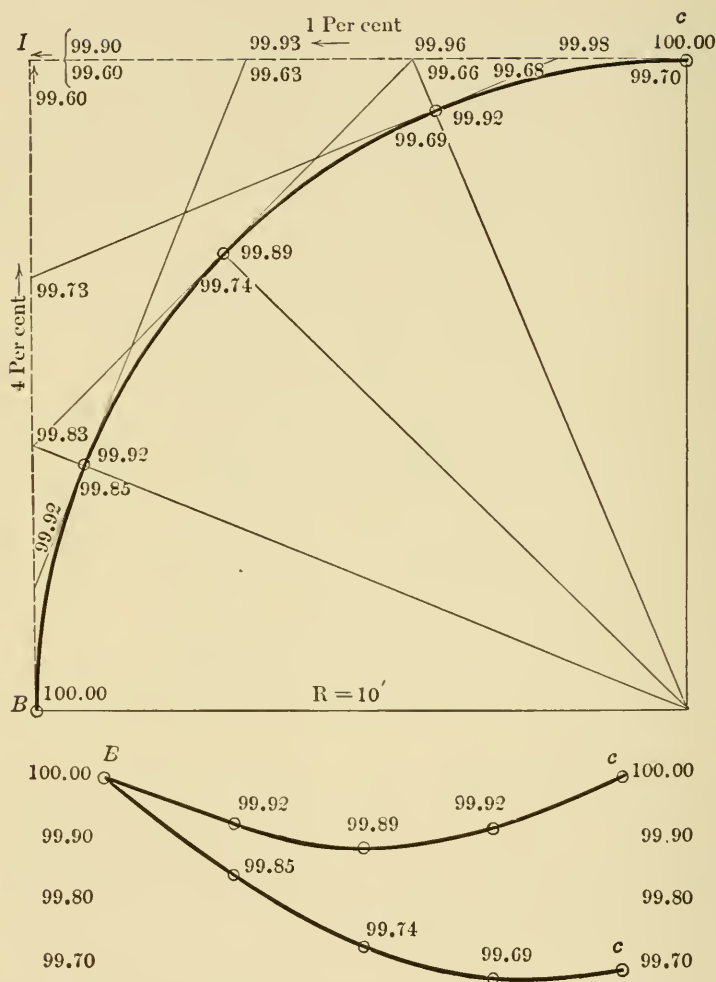


FIG. 69b.—Method of merging a grade line on one street into a grade line on another street. Where there are two elevations written at one point, the upper ones relate to $B = 100$ and $c = 100$; the lower to $B = 100$ and $c = 99.70$.

tangents. Laying off on these latter the distances to their tangent points establishes the circular curb elevations.

The maximum permissible difference in elevations at the intersection, in plan of the grade tangents, is obtained when the tangent point elevations are equal. This difference at the intersection may be decreased to zero which gives the maximum permissible difference in elevations at the tangent points. In Fig. 69*b*, the maximum difference at *I* equals 0.3 ft. and, when this is reduced to zero the elevations along the connecting curb line are lowered as indicated by the second set of figures with 100 as the elevation of *B*, and 99.70 for *c*. Profiles along the curb for the two sets of elevations are shown at the bottom of the figure. If the 4 per cent and 1 per cent grades were ascending toward the corner instead of descending these profiles would apply if turned over so as to be convex upward instead of concave.

The profile with tangent points at equal elevations is usually a good one to use when it is necessary to provide for a catch basin at a corner. The profile at the other extreme (that is, with the grade lines intersecting in a single elevation at *I*) merges best with the longitudinal grades on the tangents. Often a profile has to be chosen lying between the two extremes, the choice being a compromise.

Returning to Fig. 69*a*, while the necessity of a catch basin between *c* and *B* is one reason for not placing *c* lower than *B*, another reason is that, to do so would make a slight depression that would interfere somewhat with smooth passage from the 30-ft. roadway across the 40-ft. roadway.

Having tentatively determined the elevations at the corner of the intersection chosen for a point of beginning, the first question to be decided is, what cross-section to use for the 30-ft. roadway. The 40-ft. roadway is on the more important of the two streets and it is desired to carry it through with as little change in its 4 per cent longitudinal grade as practicable. This means that the right-hand gutter of the 30-ft. roadway has to be higher than the opposite gutter. The maximum extra elevation that can be given is obtained by the use of a section having a mean cross slope of one-half ($T + \frac{1}{2}T$) or 3 per cent, which gives a drop across the 30-ft. roadway of 0.9 ft. A cross-section continuously falling from one gutter, across the roadway, to the other, is somewhat objectionable from the standpoint of appearance, unless the general lay of the land is steep—steeper than the 4 per cent of the present

instance. A shape as much rounded as practicable should be given a roadway and the cross-section drawn with a full line, Fig. 70a, will be tried, which gives a fall from *c* to *C* of but 0.3 ft.

Now, if *L* on the 40-ft. roadway, across the intersection, is maintained at 4 per cent, the drop from *B* to *A* is 2.0 ft., thus giving a drop from *C* to *A* of 1.7 ft. and making the sidewalk slope so steep as to be objectionable. A 10 per cent sidewalk

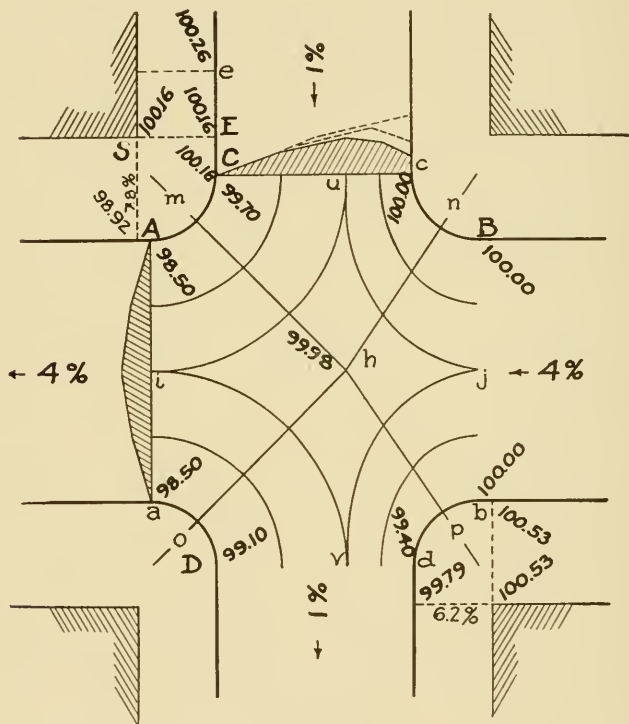


FIG. 70a.—Working out the details for an intersection.

slope, though it may be exceeded under exceptional conditions, should ordinarily be assumed as a limit for corner locations at a simple intersection such as the present one. It is to be decided whether to reduce the sidewalk slope by lowering *C* or by raising *A*; the former by changing the shape of the cross-section *Cc*, the latter by reducing *L* from *B* to *A*. A reduction in *L* across the intersection increases *L* on the 40-ft. roadway traversing the block beyond the intersection. On important

traffic highways, in cases where the grade is close to the maximum, and accordingly any increase would be objectionable, grades have been used as steep as 5 per cent across minor street intersections. Generally though, a 3 per cent limit should be adopted, which in the present example, based on a gutter elevation of 100 at tangent point *B*, gives a gutter elevation of 98.5 at *A*. A drop of 0.3 ft. from *c* to *C* gives a gutter elevation at the latter point of 99.7. A curb height of 0.5 ft. may be used at *A* and 0.4 ft. at *C*, thus taking up 0.1 ft. of their difference in elevation, and leaving 1.1 ft.

If *S* is the intersection of the building lines, a level line from *E* on the curb of the 30-ft. roadway gives a tentative elevation for *S*, since generally it is desirable to have *S* at least no lower than *E*. An elevation of 100.16 for *S* gives a slope of 7.8 per cent from *S* to the curb on the 40-ft. roadway. Other features of the intersection being properly taken care of it is well to have this slope as much less than 10 per cent as is practicable. If a satisfactory sidewalk slope above *A* can be obtained in no other manner, the break in the slope, which has been assumed along the line *SE*, may be moved further up the street, for instance to *e* at elevation 100.26. This would mean that for the small area of sidewalk between this latter break and *SE*, drainage would be toward the building line. Even if there were an opening into a building just above *S*, a slight step-up at the entrance would stop water from flowing in, and since the slope past *S* and toward *A* is steep, drainage would be well taken care of. If buildings are well set back from the sidewalks and only parking lines intersect at *S*, a coping between the grass and the walk would direct water from *e* at elevation 100.26, past *S*; and in such cases it is very common to find the break in the slope a number of feet up-hill from the line *SE*.

The next step is to decide on the cross-section of the 40-ft. roadway. This decision depends somewhat upon the lay of the land on either side of the street, but in view of the fact that the intersecting street is on only a 1 per cent grade, undoubtedly a symmetrical section will be satisfactory. Accordingly, with a gutter elevation of 98.5 at *A*, we may decide upon 98.5 for *a*. At *B* the gutter elevation is 100 and at *b*, also 100.

In making an assumption for the gutter elevation at *D*, it is desirable to have it such that a line drawn from *C* to *D* continues the 1 per cent grade. This gives 99.10 as the elevation of *D*.

From D to d the same roadway cross-section is used as was adopted for Cc , and the gutter elevation at d is 99.40. It should be noted that the tangent points C , c , D and d , lie in a plane, and also that A , a , B and b lie in a plane.

With the gutter elevations established, the next problem is to warp the surface of the 30-ft. roadway into that of the 40-ft. roadway. Circular curves are drawn between the grade lines in the roadways, connecting points in the sections Aa , Bb , Cc , Dd . Elevations along these connecting curves are determined as in Fig. 69b, leaving in the center of the intersection a space still undetermined. This space is controlled by the central point h . Sections mhp , nho , uhv , and ihj all pass through the point h , and it is an easy matter to determine an elevation for this central point that will provide satisfactory shapes

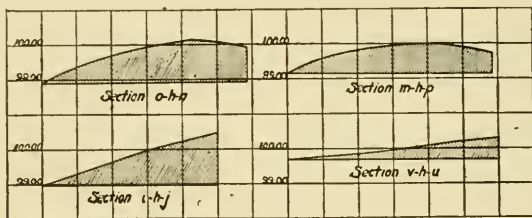


FIG. 70b.—Sections through the center point h of Fig. 70a.

for these sections. These sections are shown in Fig. 70b. Of course, as with many others of the details that have been explained, the elevation chosen for h is a matter of judgment, but as soon as the contours are drawn any desirable improvements become apparent, and then even the elevations of points previously determined on the connecting circular curves may be altered.

Figure 71 illustrates an acute intersection with a difficult grade combination. The east and west street with a 4 per cent grade is a 56-ft. Traffic Highway while the roadway of the diagonal Local Street is 30 ft. wide and is on a 6 per cent grade. Before proceeding with the discussion of grade determinations, it should be noted that the lengths of circular curb used at the four corners are equal, which balances the intersection in plan.

It is desirable to carry the Traffic Highway through the intersection with as little disturbance of its normal cross-section as practicable. While the Local Street is of secondary consideration, it may nevertheless be given quite satisfactory treatment

by attention to several small details. The hill along the side of which the Traffic Highway is located is, in this case, steep enough to justify an unsymmetrical section. The high point of the crown is placed 10 ft. from the up-hill curb and T and $\frac{1}{2} T$, in accordance with the formula, $T = 0.266 (16 - L)$, for $L = 4$ per cent, are taken as 3.2 per cent and 1.6 per cent respectively. These values are used only on the up-hill side of the crown, however; while, because of the exceptional layout

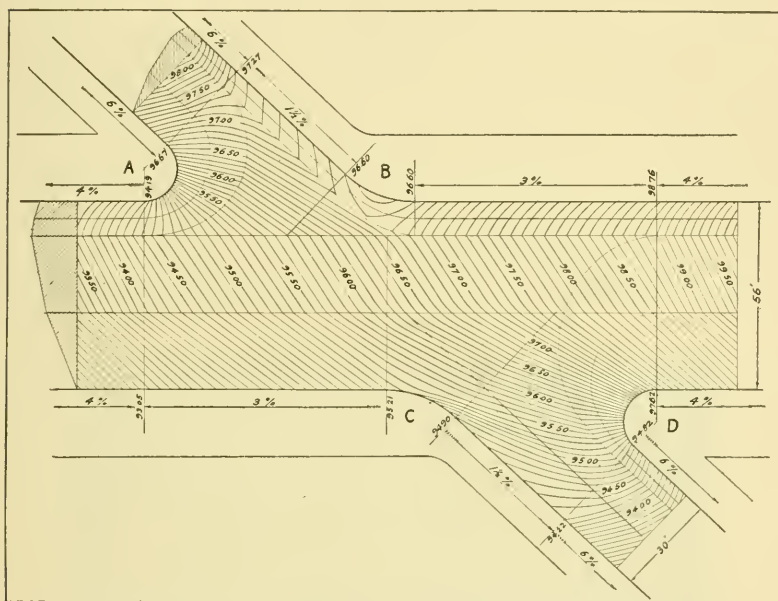


FIG. 71.—A somewhat difficult acute angle intersection.

of the intersection, 2 per cent and 4 per cent are used on the remainder of the cross-section, thus increasing what would be the normal difference in elevation between the up-hill gutter and the down-hill gutter. The cross-section of the Local Street is treated in like manner.

The intersection as developed in Fig. 71, gives close to the maximum permissible grades at the corners A and D. Undoubtedly though, at these acute corners the ground back of the sidewalks will be on such steep slopes that retaining walls will be necessary and this being the case, plenty of length may be taken for the warping of one sidewalk into the other, thus making unnecessary excessively steep grades. A hairpin turn on the

side of a hill, such as the present instance, of necessity entails more than ordinary grades on the turn; and sometimes the most practicable way to pass from the sidewalk on the lower street to that on the switchback is by means of steps.

From the figure it is seen that the Traffic Highway is favored to the extent of carrying practically one-third of its width clear through the intersection on an unbroken 3 per cent grade. It is apparent that if this were but a 1.5 per cent grade, only one-half as many contours would be crowded into the corners *A* and *D*. Through his choice of roadway cross-sections and longitudinal grades across the intersection the engineer may introduce practically any desired sidewalk grades at *A* and *D*. A feature worthy of particular notice is that the points represented by 96.67, 97.27, 96.60, 94.82, 94.22 and 94.90 all lie in one plane; similarly the points represented by 95.21, 93.05, 94.19, 96.60, 98.76 and 97.62 all lie in one plane.

109. Models for Exceptional Cases.—In exceptional cases considerable expense is justified for the construction of models to

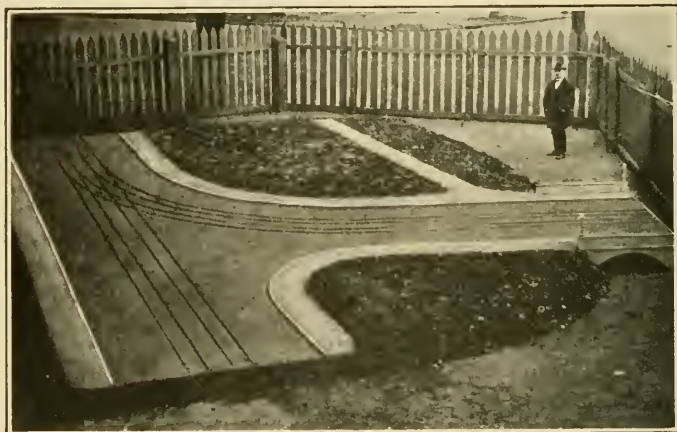


FIG. 72.—Model of Georgetown bridge approach at its intersection with the city street.

make sure that the best possible intersections are obtained. Figure 72 illustrates a model of the new Georgetown bridge approach at its intersection with one of the city streets. The street is on a 3.5 per cent down grade and the bridge approach on a 3 per cent up grade. The model is on a one-eighth scale and

its construction was necessary in order to coordinate the three interests involved; bridge, railway, and highway. Several other schemes were at first considered, all requiring a large bridge approach area with expensive track construction separated from the vehicular roadway, because prior to the construction of the model it was not evident to all that a satisfactory simple turn out, as illustrated, from the highway to the bridge, could be effected.

The model was constructed with sand, the curbs and rails of light flexible strips of wood nailed to stakes driven true to grade. The surface was given some degree of permanency by mixing a little cement with the sand.

110. Cross-sections of Alleys.—Ordinarily no curb is used with alleys and this means an inverted crown has to be used, that is,

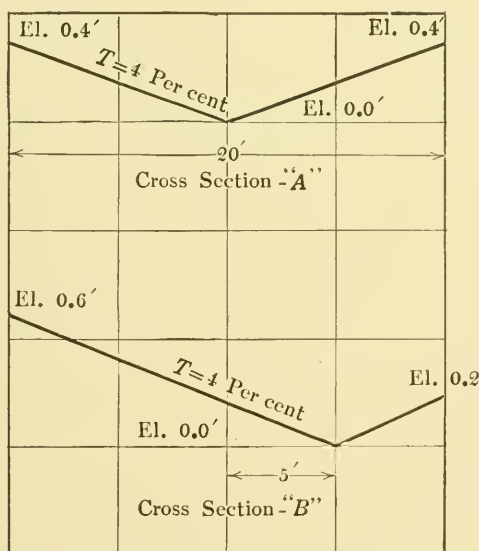


FIG. 73.—Alley cross sections.

a dished cross-section with a longitudinal gutter in the center of the alley. The cross-section can be platted by using, as shown in Fig. 73A, equal transverse slopes from the edges of the alley to the bottom of the gutter. A value for T , the transverse slope, may be obtained from the diagram, Fig. 64. For example, if the longitudinal grade = 1 per cent, $T = 4$ per cent.

If an alley is on a side slope and it is desired to have one edge higher than the other, the cross-section may be platted as in Fig. 73*B*. The horizontal distance from the low point of the gutter to the center line of the alley is obtained by the formula, $X = \frac{E}{2T}$ where E = difference in elevation, stated in hundredths of a foot, between the edges of the alley, and X = the distance in feet from the center line to the low point of the gutter. For example, if $E = 0.4$ ft. and $T = 4$ per cent, then $X = \frac{40}{2 \times 4} = 5$ ft. The gutter should not be closer to the edge than the quarter point, therefore with an alley width of 15 ft. and $T = 4$ per cent, a value for E as large as 0.4 ft. should not be used since with $X = 5$ ft. the low point of the gutter would be within $2\frac{1}{2}$ ft. of the alley edge.

Where an alley entrance is from a street that is on a steep grade there may be considerable difference in elevation from the sidewalk at the up-hill edge of the alley to the down-hill edge. Some of this difference in elevation may be taken care of by providing a step or curb along the up-hill edge, between the sidewalk and alley paving.

Merging the grades of two portions of an alley at a change in direction or intersection is done in the same manner as has been described for streets and being not nearly so difficult no further explanation is necessary. At an alley exit the alley gutter should be gradually done away with so that the transverse grades of the alley will merge with the gutter grades of the street in an unbroken straight line, thus permitting the street water to flow properly in its gutter.

111. Super-elevation of Curves.—Super-elevation of curves cannot, of course, be applied to street intersections. However, city restrictions regulate the turning of corners so that centrifugal force at the speeds attained is safely resisted by the stability of the vehicle itself. This is true even where the regulations governing left-hand turns tend to cause the crown of the roadway to increase the effect of overturning or skidding. In making right-hand turns the crown gives the same effect as super-elevation. In order to obtain this advantage, where the cutting of corners is not permitted in making a left-hand turn, regulations are sometimes violated by drivers and they hug the left-

hand curb in making the turn. The correction of this practice lies with the Police Department.

While there is little or no use for super-elevation as regards the routine street system of the city, there are generally in every municipality boulevards and parkways to which super-elevation may be applied. Super-elevation of curves is very much a matter of personal judgment. This is true even in railroad work and to a much greater extent in highway engineering. First, there is the

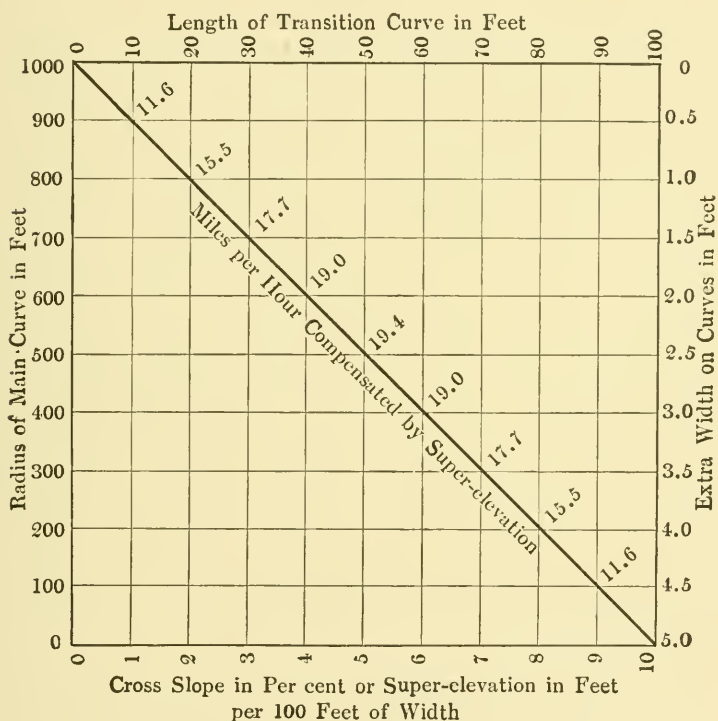


FIG. 74.—Diagram for super-elevation, transition and widening of curves.

question how much speed should be considered as cared for by the stability of the machine. There is much difference of opinion as to this but approximately 15 miles per hour appears to be a fair allowance. Thereafter, there should be need of additional compensation to the extent of no more than 19 or 20 miles per hour; but it should be noted, that all curves do not require the maximum super-elevation in order to protect traffic adequately.

Centrifugal force varies inversely as the radii of curves, and many authorities trust to the carefulness of drivers and the stability of their vehicles for curves having radii above 500 ft.; but it is a better plan to make the limit 1,000 ft., and to decrease gradually the miles per hour compensated for by super-elevation, from a maximum for a 500-ft. radius to a minimum for a 1,000-ft. curve. As the radii decreases below 500 ft. the sight distances become shorter and it is generally acknowledged that drivers decrease speed and operate their machines with care. Therefore, the miles per hour compensated by super-elevation may be decreased. Moreover, this decrease is necessary, because 10 per cent is approximately the maximum practicable cross slope that may be given a pavement in providing super-elevation.

The diagram, Fig. 74, is based upon the principles just enumerated; though it can be claimed to furnish no more than a rule-of-thumb, it does furnish with all needed accuracy, a practicable working scheme for highway purposes. The cross slopes of super-elevated sections of pavements are made to increase uniformly from zero to 10 per cent as the radii of curves decrease from 1,000 ft. to zero, that is, the super-elevation increases from zero to 1 ft. per 10 ft. of pavement width, as the radii decrease. The compensated miles per hour are a maximum of 19.4 for curves of 500-ft. radii and decrease in reasonable amounts for curves with radii above and below this length. There should generally be but little use for the portion of this diagram pertaining to curves of less than 200-ft. radius. While super-elevation is an aid in making reasonable speeds safe on crowded roadways, one of the most effective means for so doing is to keep the radius of curvature and the sight distance as much above 200 ft. as practicable.

In developing a super-elevated curve, a flat cross-section is habitually used, with a uniform slope from the high or outside edge to the low or inside edge. Generally, this slope is obtained by rotating the cross-section about the roadway center line, which is kept true to the original grade; rather than by rotating about the inside or low edge which would obtain the super-elevation entirely by raising the outside edge thereby increasing the fill. On the other hand, there are four different methods used in developing the super-elevation, one being to develop it along the tangent; another completely after the curve has been reached; a third, partly on the tangent and partly on the curve; and a fourth,

on a transition curve place between the tangent and the main curve. The method using the transition curve gives the best results.

112. Transition Approaches.—Because of the gradual reduction in the radii of a transition curve, super-elevation can be gradually carried out from the tangent to the main curve. This, in conjunction with the fact that a transition curve gives some space within which vehicles may be adjusted to the curvature, adds to both the safety and comfort of drivers. The flat cross-section which is commonly used for super-elevated pavements should be developed along the tangent prior to reaching the transition curve. By holding the crown line true to grade and gradually raising the edges of the pavement (0.1 ft. per 10 ft. is usually sufficient) this change can be made quite satisfactorily. The length of transition curve during which this flat section may be gradually tilted until the full slope of the main curve is reached should be large if the main curve has a short radius and should be less for curves of longer radius.

As with other matters pertaining to super-elevation experience has developed no generally adopted lengths for transition curves. In the diagram, Fig. 74, the lengths of transition curves are shown to decrease from 100 ft. to zero as the radii of the main curves increase from zero to 1,000 ft. and this is approximately a mean of current practice. The transition may be a compound circular curve with a linear increase in the super-elevation from the tangent to the point of full curvature. Also spiral transition as common in railroad engineering may be used. Another plan, and simplest of all, is to use a parabola from tangent to tangent; thus in one curve combining the transition and full curvature. In this case the super-elevation is easily developed by the use of a vertical parabola, along the outside edge of the pavement with the apex of the vertical curve at the apex of the horizontal one.

113. Extra Width on Curves.—Some extra width on curves is necessary because the rear wheels of most vehicles are fixed, and therefore travel on different paths than the front ones. Unless a vehicle is unreasonably long and the curve sharp, the theoretical extra width called for on this basis is slight; nevertheless, an extra margin has to be allowed to satisfy the timidity of many drivers. Where properly designed transition approaches are installed no more than 5 ft. should be allowed for extra width on sharp curves and the allowance may be reduced for curves of

longer radii. The diagram, Fig. 74, shows a decrease in this extra width from 5 ft. to zero as the radii of curves increase from zero to 1,000 ft.

Extra width cannot make up for the lack of transition approaches. When an attempt is made to do so, it may be seen, by watching the tracks of vehicles, that drivers use the extra width only to work out their own transitions; a large area of the pavement is not used, and the money spent for its construction is wasted.

PART III
CONCRETE

CHAPTER VII

CEMENT

114. Specifications.—At the present time, due to its superiority, cheapness and availability, practically the only hydraulic cement used for pavements is that known as portland cement. Among the most important properties of cement are its strength as a binding medium and its durability. Since there are no means of directly measuring these properties, it is necessary to set certain limits upon the composition and physical properties which have been found by experience to furnish a cement of good quality.

For several years departments of the United States Government worked jointly with representatives of various technical societies in the preparation of standard specifications and tests. The results of this work have been published in *Circular 33* of the Bureau of Standards, 1917, as amended, and also in *Specifications C9-21*, of the American Society for Testing Materials. These results are not final and the specifications are subject to revision from time to time as improvements are made in cement, in the methods of testing and in technical knowledge of the material. For instance, portland cement may contain a large percentage of material now worthless which could be made useful by finer grinding; but the expense under present conditions is not justified, though it may be some time in the future. Also, there are special products on the market, high strength, quick setting, and other exceptional cements. For ordinary portland cement, while there are some differences of opinion as to the substance and form of the standard specifications, everyone should adhere to them for they represent the best judgment of authoritative bodies.

A generally recognized uniform specification for portland cement is of great benefit. Highway engineers need only make reference to the standard in drawing up their specification, as for example:

Cement shall be tested by the Bureau of Highways prior to use in accordance with the *Standard Specifications and Tests, C9-21* of the American Society for Testing Materials, for portland cement (*Circular 33*, Bureau of Standards). After being tested by the Bureau of High-

ways, cement cannot be transferred or used by the contractor on other work without the consent of the engineer of highways. The contractor may keep the cement in storage under proper protection until it is used. No cement shall be used which has been injured by age or exposure.

Arrangements can sometimes be made, by paying a charge for bin storage, to test all cement at the mill. In this manner, it can be used directly on receipt at the work, without either delay or rehandling. This method is particularly adaptable where municipal officials buy all cement used for city work and furnish it to the various contractors at prices stipulated in the specifications. Contractors doing work for the United States can usually obtain cement "bin tested" by the Bureau of Standards.

It is to be regretted that other details of pavement construction have not as yet been put on as stable a basis as the "standard specifications." These are given in small print in the following paragraphs, and are accompanied by the Bureau of Standards comments thereon.

115. Definition.—Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

116. Packages and Marking.—The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 lb. net. A barrel shall contain 376 lb. net.

Packages varying more than 5 per cent from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random is less than that specified, the entire shipment may be rejected.

117. Storage.—The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

118. Inspection.—Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least 10 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically so ordered.

119. Rejection.—The cement may be rejected if it fails to meet any of the requirements of these specifications.

120. Number of Samples.—Tests may be made on individual or composite samples as may be ordered. Each test sample should weigh at least 8 lb.

(a) *Individual Sample.*—If sampled in cars one test sample shall be taken from each 50 bbl. or fraction thereof. If sampled in bins one sample shall be taken from each 100 bbl.

(b) *Composite Sample.*—If sampled in cars one sample shall be taken from 1 sack in each 40 sacks (or 1 bbl. in each 10 bbl.) and combined to form one test sample. If sampled in bins or warehouses, one test sample shall represent not more than 200 bbl.

121. Method of Sampling.—Cement may be sampled at the mill by any of the following methods that may be practicable, as ordered:

(a) *From the Conveyor Delivering to the Bin.*—At least 8 lb. of cement shall be taken from approximately each 100 bbl. passing over the conveyor.

(b) *From Filled Bins by Means of Proper Sampling Tubes.*—Tubes inserted vertically may be used for sampling cement to a maximum depth of 10 ft. Tubes inserted horizontally may be used where the construction of the bin permits. Samples shall be taken from points well distributed over the face of the bin.

(c) *From Filled Bins at Points of Discharge.*—Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement contained in the bin, as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before drawing of the cement is started.

122. Treatment of Samples.—Samples preferably shall be shipped and stored in air-tight containers. Samples shall be passed through a sieve having 20 meshes per linear inch in order to thoroughly mix the sample, break up lumps, and remove foreign materials.

123. Specification for Chemical Limits.—The following limits shall not be exceeded:

	PER CENT
Loss on ignition.....	4.00
Insoluble residue.....	0.85
Sulfuric anhydride (SO ₃)..	2.00
Magnesia (MgO).....	5.00

124. Loss on Ignition. METHOD.—One gram of cement shall be heated in a weighed covered platinum crucible of 20 to 25-c.c. capacity, as follows, using either method (a) or (b) as ordered:

(a) The crucible shall be placed in a hole in an asbestos board, clamped horizontally so that about three-fifths of the crucible projects below and blasted at a full red heat for 15 min. with an inclined flame; the loss in weight shall be checked by a second blasting for 5 min.

Care shall be taken to wipe off particles of asbestos that may adhere to the crucible when withdrawn from the hole in the board. Greater neatness and shortening of the time of heating are secured by making a hole to fit the crucible in a circular disk of sheet platinum and placing this disk over a somewhat larger hole in an asbestos board.

(b) The crucible shall be placed in a muffle at any temperature between 900 and 1,000°C. for 15 min. and the loss in weight shall be checked by a second heating for 5 min.

PERMISSIBLE VARIATION.—A permissible variation of 0.25 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 4 per cent.

125. Insoluble Residue. **METHOD.**—To a 1 g. sample of cement shall be added 10 c.c. of water and 5 c.c. of concentrated hydrochloric acid; the liquid shall be warmed until effervescence ceases. The solution shall be diluted to 50 c.c. and digested on a steam bath or hot plate until it is evident that decomposition of the cement is complete. The residue shall be filtered, washed with cold water, and the filter paper and contents digested in about 30 c.c. of a 5 per cent solution of sodium carbonate, the liquid being held at a temperature just short of boiling for 15 min. The remaining residue shall be filtered, washed with cold water, then with a few drops of hot hydrochloric acid, 1:9, and finally with hot water, and then ignited at a red heat and weighed as the insoluble residue.

PERMISSIBLE VARIATION.—A permissible variation of 0.15 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 0.85 per cent.

126. Sulfuric Anhydride. **METHOD.**—One gram of the cement shall be dissolved in 5 c.c. of concentrated hydrochloric acid diluted with 5 c.c. of water, with gentle warming; when solution is complete 40 c.c. of water shall be added, the solution filtered, and the residue washed thoroughly with water. The solution shall be diluted to 250 c.c., heated to boiling, and 10 c.c. of a hot 10 per cent solution of barium chloride shall be added slowly, drop by drop, from a pipette and the boiling continued until the precipitate is well formed. The solution shall be digested on the steam bath until the precipitate has settled. The precipitate shall be filtered, washed, and the paper and contents placed in a weighed platinum crucible and the paper slowly charred and consumed without flaming. The barium sulfate shall then be ignited and weighed. The weight obtained multiplied by 34.3 gives the percentage of sulfuric anhydride. The acid filtrate obtained in the determination of the insoluble residue may be used for the estimation of sulfuric anhydride instead of using a separate sample.

PERMISSIBLE VARIATION.—A permissible variation of 0.10 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 2 per cent.

127. Magnesias. METHOD.—To 0.5 g. of the cement in an evaporating dish shall be added 10 c.c. of water to prevent lumping and then 10 c.c. of concentrated hydrochloric acid. The liquid shall be gently heated and agitated until attack is complete. The solution shall then be evaporated to complete dryness on a steam or water bath. To hasten dehydration the residue may be heated to 150 or even 200°C. for $\frac{1}{2}$ to 1 hr. The residue shall be treated with 10 c.c. of concentrated hydrochloric acid diluted with an equal amount of water. The dish shall be covered and the solution digested for 10 min. on a steam bath or water bath. The diluted solution shall be filtered and the separated silica washed thoroughly with water.¹ Five cubic centimeters of concentrated hydrochloric acid and sufficient bromine water to precipitate any manganese which may be present, shall be added to the filtrate (about 250 c.c.). This shall be made alkaline with ammonium hydroxide, boiled until there is but a faint odor of ammonia, and the precipitated iron and aluminum hydroxides, after settling, shall be washed with hot water, once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate shall be transferred by a jet of hot water to the precipitating vessel and dissolved in 10 c.c. of hot hydrochloric acid. The paper shall be extracted with acid, the solution and washings being added to the main solution. The aluminum and iron shall then be reprecipitated at boiling heat by ammonium hydroxide and bromine water in a volume of about 100 c.c., and the second precipitate shall be collected and washed on the filter used in the first instance if this is still intact. To the combined filtrates from the hydroxides of iron and aluminum, reduced in volume if need be, 1 c.c. of ammonium hydroxide shall be added, the solution brought to boiling, 25 c.c. of a saturated solution of boiling ammonium oxalate added, and the boiling continued until the precipitated calcium oxalate has assumed a well-defined granular form. The precipitate after 1 hr. shall be filtered and washed, then with the filter shall be placed wet in a platinum crucible, and the paper burned off over a small flame of a bunsen burner; after ignition it shall be redissolved in hydrochloric acid and the solution diluted to 100 c.c. Ammonia shall be added in slight excess and the liquid boiled. The lime shall then be reprecipitated by ammonium oxalate, allowed to stand until settled, filtered, and washed. The combined filtrates from the calcium precipitates shall be acidified with hydrochloric acid, concentrated on the steam bath to about 150 c.c., and made slightly alkaline with ammonium hydroxide, boiled and filtered (to remove a little aluminum and iron and perhaps calcium). When cool, 10 c.c. of saturated solution of sodium-ammonium-hydrogen phosphate shall be added with constant stirring. When the crystallin ammonium-magnesium orthophosphate has formed, ammonia shall be added in moderate excess.

¹Since this procedure does not involve the determination of silica, a second evaporation is unnecessary.

The solution shall be set aside for several hours in a cool place, filtered and washed with water containing 2.5 per cent NH_3 . The precipitate shall be dissolved in a small quantity of hot hydrochloric acid, the solution diluted to about 100 c.c., 1 c.c., of a saturated solution of sodium-ammonium hydrogen phosphate added, and ammonia drop by drop, with constant stirring, until the precipitate is again formed as described and the ammonia is in moderate excess. The precipitate shall then be allowed to stand about 2 hr., filtered and washed as before. The paper and contents shall be placed in a weighed platinum crucible, the paper slowly charred, and the resulting carbon carefully burned off. The precipitate shall then be ignited to constant weight over a Meker burner, or a blast not strong enough to soften or melt the pyrophosphate. The weight of magnesium pyrophosphate obtained multiplied by 72.5 gives the percentage of magnesia. The precipitate so obtained always contains some calcium and usually small quantities of iron, aluminum, and manganese as phosphates.

PERMISSIBLE VARIATION.—A permissible variation of 0.4 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 5.00 per cent.

128. Interpretation of Chemical Properties.—The composition of normal portland cement has been the subject of a great deal of investigation, and it can be said that the quantities of silica, alumina, oxide of iron, lime, magnesia, and sulfuric anhydride can vary within fairly wide limits without materially affecting the quality of the material.

A normal American portland cement which meets the standard specifications for soundness, setting time, and tensile strength has an approximate composition within the following limits:

	PER CENT
Silica.....	19-25
Alumina.....	5-9
Iron oxide.....	2-4
Lime.....	60-64
Magnesia.....	1-5
Sulfur trioxide.....	1-2.00
Loss on ignition.....	0.5-3 00
Insoluble residue.....	0.1-0.85

It is also true that a number of cements have been made both here and abroad which have passed all standard physical tests in which these limits have been exceeded in one or more particulars, and it is equally true that a sound and satisfactory cement does not necessarily result from the above composition.

It is probable that further investigation will give a clearer understanding of the constitution of portland cement, but at present chemical analysis furnishes but little indication of the quality of the material.

Defective cement usually results from imperfect manufacture, not from faulty composition. Cement made from very finely ground material, thoroughly mixed and properly burned, may be perfectly sound when containing more than the usual quantity of lime, while a cement low in lime may be entirely unsound due to careless manufacture.

The analysis of a cement will show the uniformity in composition of the product from individual mills, but will furnish little or no indication of the quality of the material. Occasional analysis should, however, be made for record and to determine the loss on ignition and the quantity of sulfuric anhydride, magnesia, and insoluble residue present.

The ground clinker as it comes from the mill is usually quick setting, which requires correction. This is usually accomplished by the addition of a small quantity of more or less hydrated calcium sulphate, either gypsum or plaster of paris. The maximum limit for sulfuric anhydride (SO_3) is 2 per cent, which is considered the maximum quantity necessary to control setting properties.

The specification prohibits the addition of any material subsequent to calcination except water and calcined or uncalcined gypsum, which latter is permitted to regulate the time of set. Other additions may be difficult or impossible to detect even by a careful mill inspection during the process of manufacture, but as the normal adulterant would be ground raw material, an excess of "insoluble residue" would reveal the addition of siliceous material, and an excess in "loss on ignition" would point to the addition of calcareous material when either is added in sufficient quantity to make the adulteration profitable.

The effect of relatively small quantities of magnesia (MgO) in normal portland cement, while still under investigation, can be considered harmless. Earlier investigators believed that as magnesia had a slower rate of hydration than lime the hydration of any free magnesia (MgO) present would occur after the cement had set and cause disintegration.

The effect of magnesia was considered especially injurious when the cement was exposed to the action of sea water. More recent

investigation has shown that cement can be made which is perfectly sound under all conditions when containing 5 per cent of magnesia, and it has also been found that the lime in portland cement exposed to sea water is replaced by magnesia.

The maximum limit for magnesia has been set at 5 per cent, as it has been established that this quantity is not injurious and it is high enough to permit the use of the large quantities of raw material available in most sections of the country.

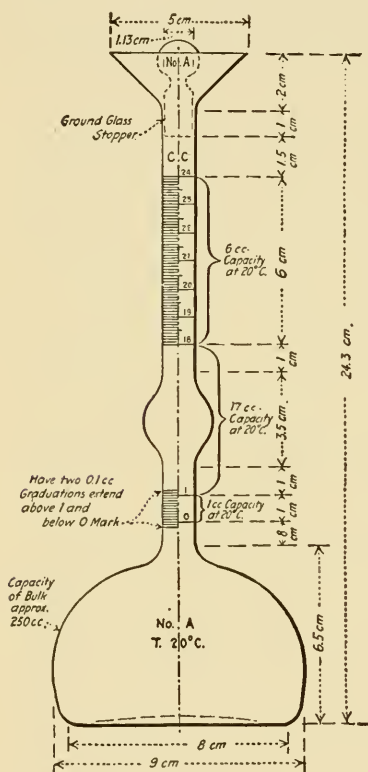


FIG. 75.

129. Specification for Specific Gravity.—The specific gravity of cement shall be not less than 3.10 (3.07 for white portland cement). Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

130. Determination of Specific Gravity. **APPARATUS.**—The determination of specific gravity shall be made with a standardized Le Chatelier apparatus which conforms to the requirements illustrated in Fig. 75. This apparatus is standardized by the U. S. Bureau of Standards. Kerosene free from water, or benzine not lighter than 62° Bé., shall be used in making this determination.

METHOD.—The flask shall be filled with either of these liquids to a point on the stem between zero and 1 c.c. and 64 g. of cement, of the same temperature as the liquid, shall be slowly introduced, taking care that the cement does not adhere to the inside of the flask above the liquid and to free the cement from air by rolling the flask in an inclined position. After all the cement is introduced, the level of the liquid will rise to some division of the graduated neck; the difference between readings is the volume displaced by 64 g. of the cement.

The specific gravity shall then be obtained from the formula:

$$\text{Specific gravity} = \frac{\text{Weight of cement (gram)}}{\text{Displaced volume (cubic centimeter)}}$$

The flask, during the operation, shall be kept immersed in water, in order to avoid variations in the temperature of the liquid in the flask, which shall not exceed $0^{\circ}.5\text{C}$. The results of repeated tests should agree within 0.01.

The determination of specific gravity shall be made on the cement as received; if it falls below 3.10, a second determination shall be made after igniting the sample as described under "Loss on Ignition."

131. Interpretation of Specific Gravity.—The specific gravity of a portland cement is not an indication of its cementing value. It will vary with the constituents of the cement, especially with the content of iron oxide. Thus the white or very light portland cements, containing only a fraction of a per cent of iron oxide, usually have a comparatively low specific gravity ranging from 3.05 to 3.15, while a cement containing 3 to 4 per cent or more of iron oxide may have a specific gravity of 3.20 or even higher. It is materially affected by the temperature and duration of burning the cement, the hard burned cement having the higher specific gravity. A comparatively low specific gravity does not necessarily indicate that a cement is underburned or adulterated, as large percentages of raw materials could be added to a cement with a normally high specific gravity before the gravity would be reduced below 3.10.

If a portland cement fresh from the mill normally has a comparatively low specific gravity, upon aging it may absorb sufficient moisture and carbon dioxide to reduce the gravity below 3.10. It has been found that this does not appreciably affect the cementing value of the material; in fact, many cements are unsound until they have been aged.

The value of the specific gravity determination lies in the fact that it is easily made in the field or laboratory, and when the normal specific gravity of the cement is known, any considerable variation in quality due to underburning or the addition of foreign materials may be detected.

132. Specification for Fineness.—The residue on a standard No. 200 sieve shall not exceed 22 per cent by weight.

Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100°C . for 1 hr., it meets this requirement.

133. Determination of Fineness. APPARATUS.—Wire cloth for standard sieves for cement shall be woven (not twilled) from brass, bronze, or other suitable wire, and mounted without distortion on frames

not less than $1\frac{1}{2}$ in. below the top of the frame. The sieve frames shall be circular, approximately 8 in. in diameter, and may be provided with a pan and cover.

A standard No. 200 sieve is one having nominally an 0.0029-in. opening and 200 wires per inch standardized by the U. S. Bureau of Standards, and conforming to the following requirements:

The No. 200 sieve should have 200 wires per inch, and the number of wires in any whole inch shall not be outside the limits of 192 to 208. No opening between adjacent parallel wires shall be more than 0.0050 in. in width. The diameter of the wire should be 0.0021 in. and the average diameter shall not be outside the limits 0.0019 to 0.0023 in. The value of the sieve as determined by sieving tests made in conformity with the standard specification for these tests on a standardized cement which gives a residue of 25 to 20 per cent on the No. 200 sieve, or on other similarly graded material, shall not show a variation of more than 1.5 per cent above or below the standards maintained at the Bureau of Standards.

METHOD.—The test shall be made with 50 g. of cement. The sieve shall be thoroughly clean and dry. The cement shall be placed on the No. 200 sieve, with pan and cover attached, if desired, and shall be held in one hand in a slightly inclined position so that the sample will be well distributed over the sieve, at the same time gently striking the side about 150 times per minute against the palm of the other hand on the up stroke. The sieve shall be turned every 25 strokes about one-sixth of a revolution in the same direction. The operation shall continue until not more than 0.05 g. passes through in 1 min. of continuous sieving. The fineness shall be determined from the weight of the residue on the sieve expressed as a percentage of the weight of the original sample.

Mechanical sieving devices may be used, but the cement shall not be rejected if it meets the fineness requirement when tested by the hand method.

134. Interpretation of Fineness.—Only the extremely fine powder of cement called flour possesses appreciable cementing qualities, the coarser particles adding little or nothing to the cementing value. No sieve is fine enough to determine the flour in a cement, nor is there any other generally applied means of accurately and practically measuring the flour. Some cements grind easier than others, thus, although a larger percentage of one cement may pass the 200-mesh sieve than another, the former may have a smaller percentage of actual flour due to the difference in the hardness and the character of the clinker, and the method used in grinding. Thus the cementing value of

different cements cannot be compared directly upon their apparent fineness through a 200-mesh sieve. With cement from the same mill, with similar clinker and grinding machinery, however, it is probable that the greater the percentage which passes the 200-mesh sieve the greater the percentage of flour in that particular cement. Data at present available indicate that all portland cements have greater cementing value as the fineness is increased.

135. Mixing Cement Pastes and Mortars. METHOD.—The quantity of dry material to be mixed at one time shall not exceed 1,000 g. nor be less than 500 g. The proportions of cement or cement and sand shall be stated by weight in grams of the dry materials; the quantity of water shall be expressed in cubic centimeters (1 c.c. of water = 1 g.). The dry materials shall be weighed, placed upon a non-absorbent surface, thoroughly mixed dry if sand is used, and a crater formed in the center, into which the proper percentage of clean water shall be poured; the material on the outer edge shall be turned into the crater by the aid of a trowel. After an interval of $\frac{1}{2}$ min. for the absorption of the water the operation shall be completed by continuous, vigorous mixing, squeezing and kneading with the hands for at least 1 min. During the operation of mixing, the hands should be protected by rubber gloves.

The temperature of the room and the mixing water shall be maintained as nearly as practicable at 21°C. (70°F.).

136. Careful Mixing Necessary.—In order to secure uniformity in the results of tests for the time of setting and tensile strength the manner of mixing above described should be carefully followed. At least 1 min. is necessary to obtain the desired plasticity which is not appreciably affected by continuing the mixing for several minutes. The exact time necessary is dependent upon the personal equation of the operator. The error in mixing should be on the side of over-mixing.

The homogeneity of the cement paste or mortar is dependent upon the thoroughness of the mixing, and this may have considerable influence upon the time of setting and the strength of the briquettes. Concordant results can be obtained only by using extreme care in mixing the paste or mortar.

137. Normal Consistency. APPARATUS.—The Vicat apparatus consists of a frame *A*, Fig. 76, bearing a movable rod *B*, weighing 300 g., one end *C* being 1 cm. in diameter for a distance of 6 cm., the other having a removable needle *D*, 1 mm. in diameter, 6 cm. long. The rod is reversible, and can be held in any desired position by a screw *E*, and

has midway between the ends a mark *F* which moves under a scale (graduated to millimeters) attached to the frame *A*. The paste is held in a conical, hard-rubber ring *G*, 7 cm. in diameter at the base, 4 cm. high, resting on a glass plate *H* about 10 cm. square.

METHOD.—In making the determination, 500 g. of cement, with a measured quantity of water, shall be kneaded into a paste, as described under “Mixing Cement Pastes and Mortars” and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained about 6 in. apart; the ball resting in the palm of one hand shall be pressed into the larger end of the rubber

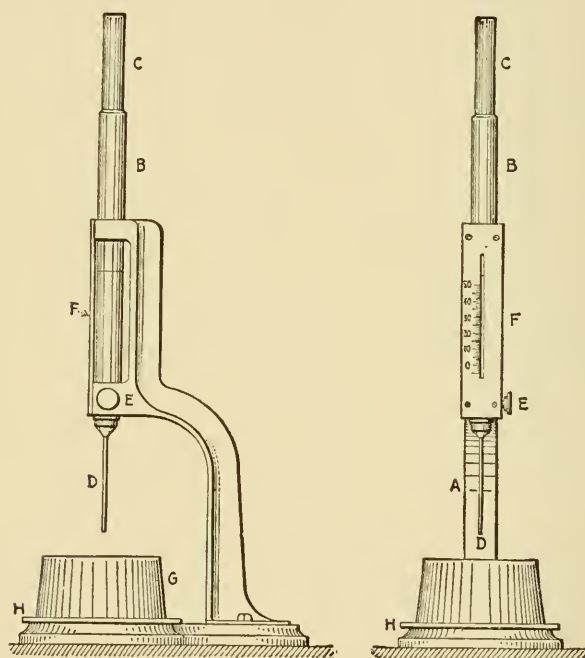


FIG. 76.—Vicat apparatus.

ring held in the other hand, completely filling the ring with paste; the excess at the larger end shall then be removed by a single movement of the palm of the hand; the ring shall then be placed on its larger end on a glass plate and the excess paste at the smaller end sliced off at the top of the ring by a single oblique stroke of a trowel held at a slight angle with the top of the ring. During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod, the larger end of which shall be brought in contact with the surface of the paste; the scale shall be then

read, and the rod quickly released. The paste shall be of normal consistency when the rod settles to a point 10 mm. below the original surface in $\frac{1}{2}$ min. after being released. The apparatus shall be free from all vibrations during the test. Trial pastes shall be made with varying percentages of water until the normal consistency is obtained. The amount of water required shall be expressed in percentage by weight of the dry cement.

The consistency of standard mortar shall depend on the amount of water required to produce a paste of normal consistency from the same sample of cement. Having determined the normal consistency of the sample, the consistency of standard mortar made from the same sample shall be as indicated in Table III, the values being in percentage of the combined dry weights of the cement and standard sand.

TABLE III.—PERCENTAGE OF WATER FOR STANDARD MORTARS

Percentage of water for neat cement paste of normal consistency	Percentage of water for one cement, three standard Ottawa sand	Percentage of water for neat cement paste of normal consistency	Percentage of water for one cement, three standard Ottawa sand
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

138. Importance of Consistency.—The quantity of water used in making the paste or mortar from which the pats for soundness, tests of setting, and the briquettes are made is very important and may vitally affect the results obtained. The determination consists in measuring the quantity of water required to bring a cement to a certain state of plasticity.

139. Specification for Soundness.—A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within 28 days thereafter.

140. Determination of Soundness. APPARATUS.—A steam apparatus which can be maintained at a temperature between 98 and 100°C., or one similar to that shown in Fig. 77, is recommended. The capacity of this apparatus may be increased by using a rack for holding the pats in a vertical or inclined position.

METHOD.—A pat from cement paste of normal consistency about 3 in. in diameter, $\frac{1}{2}$ in. thick at the center, and tapering to a thin edge, shall be made on clean glass plates about 4 in. square, and stored in moist air for 24 hr. In molding the pat the cement paste shall first be flattened on the glass and the pat then formed by drawing the trowel from the outer edge toward the center.

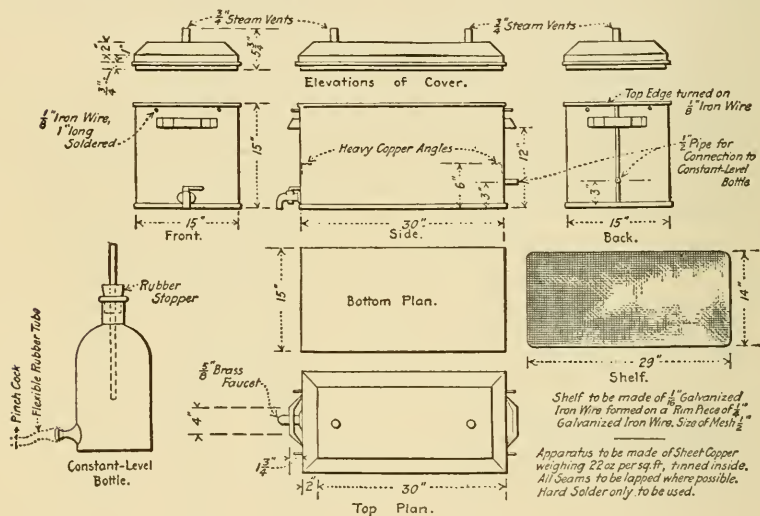


FIG. 77.

The pat shall then be placed in an atmosphere of steam at a temperature between 98 and 100°C. upon a suitable support 1 in. above boiling water for 5 hr.

Should the pat leave the plate, distortion may be detected best with a straight edge applied to the surface which was in contact with the plate.

141. Interpretation of Soundness.—The purpose of this test is to detect those qualities in a cement which tend to destroy the strength and durability. Unsoundness is usually manifested by a change in volume which causes cracking, swelling, or disintegration. If the pat is not properly made, or if it is placed where it will be subject to any drying during the first 24 hr., it may develop what are known as shrinkage cracks, which are not an indication of unsoundness and should not be confused with disintegration



Shrinkage

Shrinkage

Distortion

FIG. 78a.—Pat failures that do not necessarily indicate unsoundness.



Cracking

Checking

Disintegration

FIG. 78b.—Pat failures indicating unsoundness.

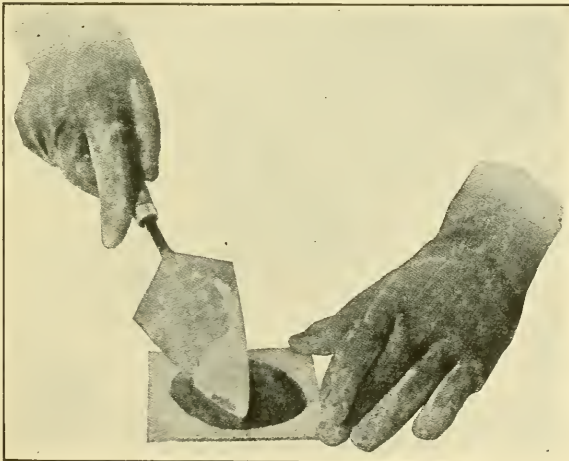


FIG. 79.—Correct method of of molding cement pat.

cracks. (See Figs. 78*a* and *b*.) No shrinkage cracks should develop after the first 24 or 48 hr. The failure of the pats to remain on the glass or the cracking of the glass to which the pat is attached does not necessarily indicate unsoundness. In molding the pats, the cement paste should first be flattened on the glass and the pat formed by drawing the trowel from the outer edge toward the center, as shown in Fig. 79.

142. Specification for Time of Setting.—The cement shall not develop initial set in less than 45 min. when the Vicat needle is used or 60 min. when the Gillmore needle is used. Final set shall be attained within 10 hr.

143. Determination of Time of Setting.—The following are alternate methods, either of which may be used as ordered:

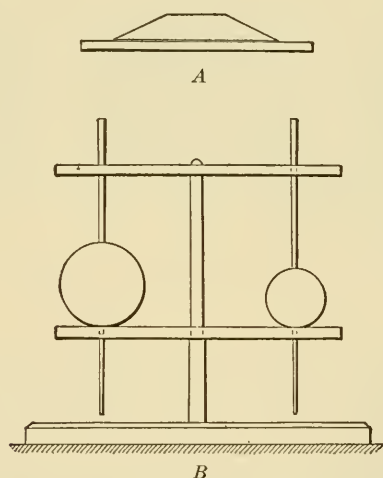


FIG. 80.—(a) Pat with top surface flattened for determining time of setting by Gillmore method. (b) Gillmore needles.

VICAT APPARATUS.—The time of setting shall be determined with the Vicat apparatus described under “Normal Consistency.”

VICAT METHOD.—A paste of normal consistency shall be molded in the hard-rubber ring *G*, as previously described and placed under the rod *B*, the smaller end of which shall then be carefully brought in contact with the surface of the paste, and the rod quickly released. The initial set shall be said to have occurred when the needle ceases to pass a point 5 mm. above the glass plate in $\frac{1}{2}$ min. after being released, and the final set when the needle does not sink visibly into the paste. The test pieces shall be kept in moist air during the test. This may be accomplished by placing them on a rack over water contained in a pan and covered by

a damp cloth, kept from contact with them by means of a wire screen; or they may be stored in a moist closet. Care shall be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point may increase the penetration. The time of setting is affected not only by the percentage and temperature of the water used and the amount of kneading the paste receives, but by the temperature and humidity of the air, and its determination is therefore only approximate.

GILLMORE NEEDLES.—The time of setting shall be determined by the Gillmore needles. The Gillmore needles should preferably be mounted as shown in Fig. 80*b*.

GILLMORE METHOD.—The time of setting shall be determined as follows: A pat of neat cement paste about 3 in. in diameter and $\frac{1}{2}$ in. in thickness with a flat top, Fig. 80*a*, mixed to a normal consistency, shall be kept in moist air at a temperature maintained as nearly as practicable at 21°C. (70°F.). The cement shall be considered to have acquired its initial set when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{12}$ in. in diameter, loaded to weigh $\frac{1}{4}$ lb. The final set has been acquired when the pat will bear without appreciable indentation, the Gillmore needle $\frac{1}{24}$ in. in diameter, loaded to weigh 1 lb. In making the test the needles shall be held in a vertical position and applied lightly to the surface of the pat.

144. Interpretation of Time of Setting.—The purpose of this test is to determine the time which elapses from the moment water is added until the paste ceases to be plastic and the time required for it to obtain a certain degree of hardness. The determination of the “initial set” or when plasticity ceases is the more important, as a disturbance of the material after this time may cause a loss of strength, and thus it is important that the mixing and molding or the incorporating of the material into the work be accomplished within this time. The time of setting by the Gillmore needles is usually determined upon the pat which is to be used for the soundness test, the top surface being flattened somewhat, as shown in Fig. 80*a*. In using the Gillmore needles care should be taken to apply the needles in a vertical position and perpendicular to the surface of the pat. The rate of setting and hardening may be materially affected by slight changes in temperature. The percentage of water used in gauging and the humidity of the moist closet in which the test pieces are stored may also affect the setting somewhat.

145. Specification for Tensile Strength.—The average tensile strength in pounds per square inch of not less than three standard mortar bri-

quettes composed of 1 part cement and 3 parts standard sand, by weight, shall be equal to or higher than the following:

Age at test, days	Storage of briquettes	Tensile strength, pounds per square inch
7	1 day in moist air, 6 days in water.	200
28	1 day in moist air, 27 days in water.	300

The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

146. Tension Tests. FORM OF TEST PIECE.—The form of test piece shown in Fig. S1, shall be used. The molds shall be made of non-cor-

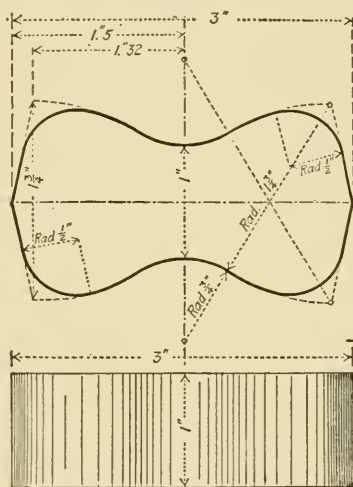


FIG. S1.—Details for briquette.

roding metal and have sufficient material in the sides to prevent spreading during molding. Gang molds when used shall be of the type shown in Fig. S2. Molds shall be wiped with an oily cloth before using.

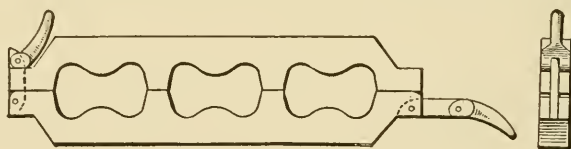


FIG. S2.—Gang mold.

STANDARD SAND.—The sand to be used shall be natural sand from Ottawa, Ill., screened to pass a No. 20 sieve and retained on a No. 30

sieve. This sand may be obtained from the Ottawa Silica Co., at a cost of 3 cts. per pound, f.o.b. cars, Ottawa, Ill.

This sand, having passed the No. 20 sieve, shall be considered standard when not more than 5 g. pass the No. 30 sieve after 1 min. continuous sieving of a 500-g. sample.

The sieves shall conform to the following specifications:

The No. 20 sieve shall have between 19.5 and 20.5 wires per whole inch of the warp wires and between 19 and 21 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0165 in. and the average diameter shall not be outside the limits of 0.0160 and 0.0170 in.

The No. 30 sieve shall have between 29.5 and 30.5 wires per whole inch of the warp wires and between 28.5 and 31.5 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0110 in. and the average diameter shall not be outside the limits 0.0105 to 0.0115 in.

MOLDING.—Immediately after mixing, the standard mortar shall be placed in the molds, pressed in firmly with the thumbs and smoothed off with a trowel without ramming. Additional mortar shall be heaped above the mold and smoothed off with a trowel; the trowel shall be drawn over the mold in such a manner as to exert a moderate pressure on the material. The mold shall then be turned over and the operation of heaping, thumbing, and smoothing off repeated.

TESTING.—Tests shall be made with any standard machine. The briquettes shall be tested as soon as they are removed from the water. The bearing surfaces of the clips and briquettes shall be free from grains of sand or dirt. The briquettes shall be carefully centered and the load applied continuously at the rate of 600 lb. per minute.

Testing machines should be frequently calibrated in order to determine their accuracy.

FAULTY BRIQUETTES.—Briquettes that are manifestly faulty, or which give strengths differing more than 15 per cent from the average value of all test pieces made from the same sample and broken at the same period, shall not be considered in determining the tensile strength.

147. Storage of Test Pieces. **APPARATUS.**—The moist closet may consist of a soapstone, slate, or concrete box, or a wooden box lined with metal. If a wooden box is used, the interior should be covered with felt or broad wicking kept wet. The bottom of the moist closet should be covered with water. The interior of the closet should be provided with non-absorbent shelves on which to place the test pieces, the shelves being so arranged that they may be withdrawn readily.

METHODS.—Unless otherwise specified, all test pieces, immediately after molding, shall be placed in the moist closet for from 20 to 24 hr.

The briquettes shall be kept in molds on glass plates in the moist closet for at least 20 hr. After 24 hr. in moist air the briquettes shall be immersed in clean water in storage tanks of non-corroding material.

The air and water shall be maintained as nearly as practicable at a temperature of 21°C. (70°F.).

148. Careful Testing Necessary.—Consistent results can be obtained only by exercising great care in molding and testing the

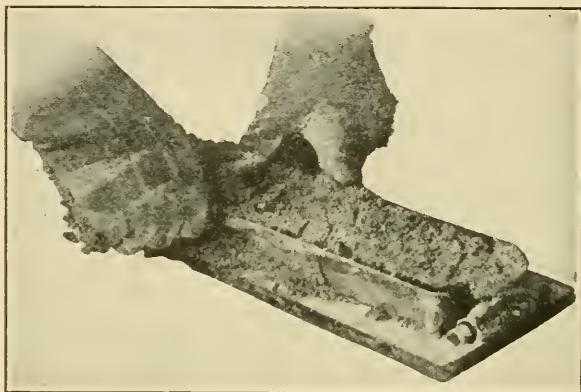


FIG. 83.—Correct method of filling briquette mold.

briquettes. The correct method of filling the mold is shown in Figs. 83 and 84. In testing the sides of the briquette and the clips should be thoroughly cleaned and free from grains of sand

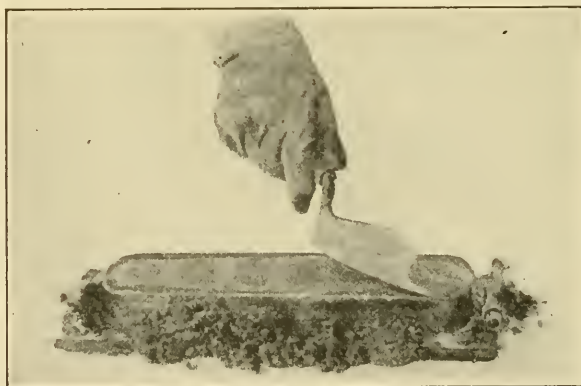


FIG. 84.—Correct method of troweling surface of briquettes.

or dirt which would prevent a good bearing and the briquette should be carefully centered in the clips so as to avoid cross strains. It may be considered good laboratory practice if the individual briquettes of any set do not show a greater variation

from the mean value than 10 per cent for sand mixtures. The 28-day mortar tests should not be omitted except in cases of emergency.

If worth-while results are to be obtained in cement testing careful and trained operators are necessary. Slight differences in manipulating the mixtures and handling the equipment may lead to widely variable results. In order to obtain information regarding the uniformity of work in various laboratories, the Bureau of Public Roads sent out samples of a certain portland cement. Tests were made in 43 states and the District of Columbia, and varied as shown in Table IV.

TABLE IV.—RESULTS OF PORTLAND CEMENT TESTS

	Minimum	Maximum
Per cent water for normal consistency.	22.0 per cent	27 per cent
Fineness retained on No. 200 sieve...	8.3 per cent	20 per cent
Time for initial set.....	1 hr. 10 min.	5 hr.
Time for final set.....	2 hr. 35 min.	7 hr. 15 min.
Tensile strength with 3 parts Ottawa sand—7 days.	271 lb. per square inch	445 lb. per square inch
Tensile strength with 3 parts Ottawa sand—28 days.	317 lb. per square inch	508 lb. per square inch

These variable results show the importance of following closely the prescribed standard methods, as only in this way can different laboratories turn out work with a fair degree of uniformity, for instance, equal to that shown in Table V.

TABLE V.—TEST RESULTS SHOWING UNIFORMITY

Laboratory	Normal consistency, per cent	Fineness retained on No. 200 sieve, per cent	Initial set	Final set	Tensile strength	
					7 days	28 days
Average of all.....	23.5	13.9	3-6	5-42	305	393
Bureau of Public Roads...	24.5	14.5	4-15	6-50	286	362
Bureau of Standards.....	22.5	12.7	3-20	6-30	346	398

149. Cost of Cement.—Most cement is handled in bags with an allowance per empty bag for return in good condition. On

account of the working conditions common to most paving jobs it is seldom that as much as 80 per cent of the bags are good enough to warrant the rebate. On some large jobs and where conditions are favorable, bulk cement may be used, thereby saving not only loss on bags not returned, but also affording cheaper handling both at the mill and on the work. The cost of cement, delivered,

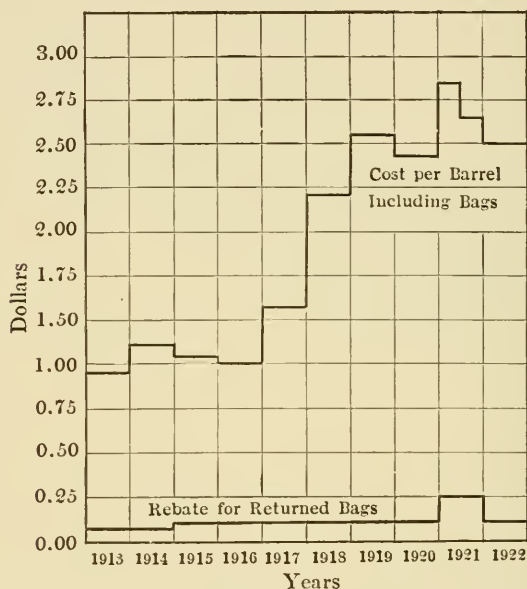


FIG. 85.—Cost of cement in the District of Columbia.

is largely affected by freight charges. Local data should be kept as illustrated in Fig. 85. This chart brings out plainly the fact that the price offered at the beginning of 1921 was excessive, particularly in view of the decline for 1920 over that of 1919. Accordingly, a 6-month contract instead of an annual one was entered into, and as the chart shows, a material saving was thereby made.

CHAPTER VIII

AGGREGATES

150. Specifications and Tests.—In general, aggregate, the inert material mixed with portland cement to make concrete is a combination of fine aggregate, in other words, sand; and coarse aggregate. The latter may be either crushed stone or gravel or similar material. Gravel will give as good results as any other material. Slag is available in immense quantities in many parts of the country and its use as coarse aggregate has been increasing rapidly in recent years.

The earliest tests of coarse aggregates were adapted directly from those made on rocks for macadam roads. Experience has shown that the tests for hardness, toughness and cementation value are of little real use in judging the quality of an aggregate for concrete, and tests made at the Research Laboratory, Lewis Institute, Chicago, show that the type and per cent of wear of the aggregate has little influence on the compressive strength or wear of the concrete. The trend at present is, therefore, toward making physical tests of the concrete rather than of the aggregate.

Thus far standard specifications and tests for aggregates have not been generally adopted. This has been because there is such a vast variety of suitable materials that make good concrete. A choice of materials is often limited to those locally available, the freight charge alone for imported materials being prohibitive. The American Society for Testing Materials in 1921 published tentative specifications for aggregates, in connection with which it is necessary to describe certain tests. American Society for Testing Materials extracts are indicated by small print.

151. Sieve Analysis.—Sieves used in laboratory work are made of woven wire with a square mesh. Those recommended by the American Society for Testing Materials are Nos. 100, 50, 30, 16, 8, 4, and $\frac{3}{8}$ -in., $\frac{3}{4}$ -in., and $1\frac{1}{2}$ -in. The width of the clear openings of each sieve is exactly double that of the next smaller one. Screens used by commercial plants have round instead of square openings. They are usually cylindrical and made of perforated steel plates. The product from such screens

may vary greatly dependent upon the condition of the equipment and the manner in which it is used.

152. Sampling.—A representative test sample of the aggregate shall be selected by quartering or by use of a sampler, which after drying will give not less than the following:

(a) Fine aggregate, 500 g.

(b) Coarse aggregate or a mixture of fine and coarse aggregates, weight in grams, 3,000 times size of largest sieve required, measured in inches.

153. Treatment of Sample.—The sample shall be dried at not over 110°C. (230°F.) to constant weight.

154. Sieves.—The sieves shall be of square-mesh wire cloth and shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sifting.

The size of wire and sieve openings shall be as given in the accompanying Table VI.

TABLE VI.—SIZE OF WIRE AND SIEVE OPENINGS

Sieve number ¹ or size in inches	Sieve opening		Wire diameter		Tolerance, per cent		
	Inches	Milli- meters	Inches	Milli- meters	Average opening	Wire diam- eter	Maxi- mum opening
No. 100	0.0059	0.149	0.0040	0.102	6	20	40
No. 50	0.0117	0.297	0.0074	0.188	6	20	40
No. 30	0.0232	0.590	0.0130	0.330	4	10	25
No. 16	0.0469	1.190	0.0213	0.540	3	10	10
No. 8	0.0937	2.380	0.0331	0.840	3	10	10
No. 4	0.1870	4.760	0.0500	1.270	3	10	10
$\frac{3}{8}$ in.	0.3750	9.500	0.0920	2.330	3	10	10
$\frac{3}{4}$ in.	0.7500	19.000	0.1350	3.420	3	10	10
1 in.	1.0000	25.400	0.1620	4.120	3	10	10
1½ in.	1.5000	38.000	0.1770	4.500	3	10	10
2 in.	2.0000	50.800	0.1920	4.880	3	10	10
3 in.	3.0000	76.000	0.2500	6.300	3	10	10

¹ Sieves No. 100 to No. 4 are based on "Table of Fundamental Data on Standard Specifications for Sieves" issued by the U. S. Bureau of Standards, 1920. The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the numbers given in the table.

155. Procedure.—The sample shall be separated into a series of sizes by means of the sieves specified. Sifting shall be continued until not more than 1 per cent by weight of the sample passes any sieve during 1 min.

Each size shall be weighed on a balance or scale which is sensitive to one-one thousandth of the weight of the test sample.

The percentage by weight of the total sample which is finer than each of the sieves shall be computed.

156. Report.—The percentage in sieve analysis shall be reported to the nearest whole number.

If more than 15 per cent of a fine aggregate is coarser than the No. 4 sieve, or more than 15 per cent of a coarse aggregate is finer than the No. 4 sieve, the sieve analysis of the portions finer and coarser than this sieve shall be reported separately.

157. Silt, Clay and Dust.—It is generally accepted that very fine particles should not be included in aggregates for concrete, though there is disagreement as to the injurious effect of such inclusion. Undoubtedly, if there is much silt present in pavement concrete it will be brought to the top in finishing and the wearing surface will be weak and friable. Artificial sands, that is those made by rolling or crushing rock, very often contain much fine dust the presence of which may be objectionable. The American Society for Testing Materials tentative specifications require that not more than 3 per cent of the fine aggregate should be removed by the decantation test, American Society for Testing Materials Standard, D74-21, which follows:

158. Scope.—This test covers the determination of the quantity of clay and silt in natural sand to be used in highway construction.

159. Treatment of Sample.—The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100 and 110°C. (212 and 230°F.).

160. Apparatus.—The pan or vessel to be used in the determination shall be substantially 9 in. (22.9 cm.) in diameter by not less than 4 in. (10.2 cm.) deep. It shall have vertical sides and be provided with a pouring lip.

161. Procedure.—A representative portion of the dry material weighing 500 g., shall be selected from the sample and placed in the pan which has been dried and accurately weighed. Sufficient water shall be poured into the pan to cover the sand (about 225 c.c.) and agitated vigorously for 15 sec. After it has settled for 15 sec. the water shall be poured off into a tared evaporating dish, care being taken not to pour off any sand. This is repeated until the wash water is clear, a glass rod being used to stir the material for the last few washings. The pan and washed sand shall be dried to constant weight in an oven at a temperature between 100 and 110°C. (212 and 230°F.), weighed and the net weight of sand determined.

162. Percentage of Clay.—The percentage of clay and silt shall be calculated from the formula:

$$\text{Percentage of clay and silt} = \frac{\text{original weight} - \text{weight after washing}}{\text{original weight}} \times 100$$

163. Check Determination.—For a check on the result, the wash water shall be evaporated to dryness and the residue weighed:

$$\text{Percentage of clay and silt} = \frac{\text{weight of residue}}{\text{original weight}} \times 100$$

In accordance with American Society for Testing Materials D72-21, gravel is tested in the same manner as sand. A larger sample is required, at least 50 times the weight of the largest stone in the sample, and the pan should be 12 in. in diameter.

164. Organic Impurities.—Organic impurities in sand are objectionable. They may either prevent or at least retard the setting and hardening of cement. Impurities generally result from carelessness in stripping the over-burden from sand and gravel pits. The calorimetric test is used for investigating organic impurities. If the liquid after settlement is colorless or at the most a light yellow it indicates freedom of organic impurities; whereas, if the liquid is a decided amber or brown it is an indication of an objectionable amount. The complete calorimetric test, American Society for Testing Materials Tentative, C40-21T, is as follows:

165. Scope.—The test herein specified is an approximate test for the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests of the sands are necessary before using them in concrete. Sands which produce a color in the sodium hydroxide solution darker than the standard color should be subjected to strength tests in mortar or concrete before use.

166. Sample.—(a) A representative test sample of sand of about 1 lb. shall be obtained by quartering or by the use of a sampler.

167. Procedure.—(b) A 12-oz. graduated glass prescription bottle shall be filled to the 4½-oz. mark with the sand to be tested.

(c) A 3 per cent solution of sodium hydroxide (NaOH) in water shall be added until the volume of sand and liquid after shaking gives a total volume of 7 liquid ounces.

(d) The bottle shall be stoppered and shaken thoroughly and then allowed to stand for 24 hr.

(e) A standard color solution shall be prepared by adding 2.5 c.c. of a 2 per cent solution of tannic acid in 10 per cent alcohol to 22.5 c.c. of a

3 per cent sodium hydroxide solution. This shall be placed in a 12-oz. prescription bottle, stoppered and allowed to stand for 24 hr., then 25 c.c. of water added.

168. Color Value.—(f) The color of the clear liquid above the sand shall be compared with the standard color solution prepared as in Paragraph (e) or with a glass of color similar to the standard solution.

Solutions darker in color than the standard color have a "color value" higher than 250 p.p.m. in terms of tannic acid.

169. Test for Unit Weight.—The test for unit weight of fine, coarse, or mixed aggregates for concrete holds an important place in studies that have been made of concretes. The following standard method, C29-21, for making the test is given by the American Society for Testing Materials.

170. Apparatus.—The apparatus required consists of a cylindrical metal measure, a tamping rod, and a scale or balance, sensitive to 0.5 per cent of the weight of the sample to be weighed.

The measure shall be of metal, preferably machined to accurate dimensions on the inside, cylindrical in form, watertight, and of sufficient rigidity to retain its form under rough usage, with top and bottom true and even, and preferably provided with handles.

The measures shall be of $\frac{1}{10}$, $\frac{1}{2}$ or 1 cu. ft. capacity, depending on the maximum diameter of the coarsest particles in the aggregate, and shall be of the dimensions given in Table VII.

TABLE VII.—DIMENSIONS OF STANDARD METAL MEASURES

Capacity, cubic feet	Inside diameter, inches	Inside height, inches	Minimum thickness of metal, U. S. gage	Diameter of largest particles of aggregate, inches
$\frac{1}{10}$	6.00	6.10	No. 11	Under $\frac{1}{2}$
$\frac{1}{2}$	10.00	11.00	No. 8	Under $1\frac{1}{2}$
1	14.00	11.23	No. 5	Over $1\frac{1}{2}$

The tamping rod shall be a straight metal rod $\frac{3}{4}$ in. in diameter and 18 in. long, with one end tapered for a distance of 1 in. to a blunt bullet-shape joint.

171. Calibrating the Measure.—The measure shall be calibrated by accurately determining the weight of water at 16.7°C. (62°F.) required to fill it. The factor for any unit shall be obtained by dividing the unit weight of water at 16.7°C. (62°F.)¹ by the weight of water at

The sample of aggregate shall be room-dry and thoroughly mixed.

¹ The unit weight of water at 16.7°C. (62°F.) is 62.355 lb. per cubic foot. 16.7°C. (62°F.) required to fill the measure.

172. Method.—(a) The measure shall be filled one-third full and the top levelled off with the fingers. The mass shall be tamped with the pointed end of the tamping rod 25 times, evenly distributed over the surface. The measure shall be filled two-thirds full and again tamped 25 times as before. The measure shall then be filled to over-flowing, tamped 25 times, and the surplus aggregate struck off, using the tamping rod as a straight edge.

In tamping the first layer the rod should not be permitted to forcibly strike the bottom of the measure. In tamping the second and final layers, only enough force to cause the tamping rod to penetrate the last layer of aggregate placed in the measure should be used. No effect should be made to fill holes left by the rod when the aggregate is damp.

(b) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described herein.

Results with the same sample should check within 1 per cent.

173. Sizes of Aggregate.—Aggregate is divided arbitrarily into fine and coarse, the gradation of each from the smallest particles to the largest being determined by means of sieves or screens. Usually, it is considered that sand should all pass the No. 4 sieve. Some engineers limit the minimum size of coarse aggregate to that retained by a $\frac{1}{4}$ -in. round-hole screen with 5 per cent tolerance. The American Society for Testing Materials recognizes a 15 per cent tolerance and this is particularly desirable in the use of gravel. In fact, if a gravel deposit is clean enough and contains such a gradation of particles as to show good concrete under test there may be no necessity for arbitrary division into fine and coarse aggregate. There are reliable records of good concrete pavements that have been made with pit-run gravel; but it is to be borne in mind that success was obtained only through effective laboratory control, the type and extent of which were fully warranted by the fact that the cost of furnishing aggregates in accordance with arbitrary specifications was unreasonably excessive. Specifications for aggregates are as follows:

174. Fine Aggregate.—Fine aggregate shall consist of sand, stone screenings, or other inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable uncoated grains, free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam or other deleterious substances.

Fine aggregate shall preferably be graded from fine to coarse, with the coarser particles predominating, within the following limits:

Passing No. 4 sieve.....	100 per cent
Passing No. 50 sieve, not more than.....	30 per cent
Weight removed by elutriation test, not more than.....	3 per cent

175. Coarse Aggregate.—Coarse aggregate shall consist of crushed stone, gravel, or other approved inert materials with similar characteristics, or a combination thereof, having clean hard, strong, durable, uncoated pieces free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter.

Coarse aggregates shall be well graded from fine to coarse within the following limits.

Passing * in. sieve (maximum size).....	100 per cent
Passing * in. sieve (intermediate size).....	* to * per cent

Not more than 15 per cent shall pass the No. 4 sieve, not more than 5 per cent shall pass a No. 8 sieve.

When there are several suitable aggregates available, a thorough investigation of the relative economy of each for producing concrete of the desired strength is advisable, especially for work of considerable magnitude.

* NOTE.—Figures to be inserted by the engineer. The grading as specified is intended to secure uniformity of aggregate, and will be governed by local conditions. Table VIII indicates desirable gradings, in percentages, for coarse aggregate for certain maximum sizes.

TABLE VIII.—PERCENTAGE GRADING OF AGGREGATE

Maximum size of aggregate, inches	Circular openings, inches								Passing screen having circular openings $\frac{1}{4}$ in. in diameter, not more than
	3	2½	2	1½	1¼	1	¾	½	
3	100	...	...	40-75	.....	.....	.....	.....	15 per cent
2½	...	100	...	.....	40-75	.....	.....	.....	15 per cent
2	...	...	100	.....	.....	40-75	.....	.....	15 per cent
1½	...	...	...	100	.....	.....	40-75	.....	15 per cent
1¼	...	...	...		100	.....	.....	35-70	15 per cent
1	...	...	...			100	.....	40-75	15 per cent
¾	...	...	...				100	.....	15 per cent

There is a tendency today to use large sizes of coarse aggregate in pavements; a number of specifications admit 4-in. aggregate. The use of such coarse pieces reduces crushing and screening costs and improves the quality of the concrete. (See Chap. X).

176. Mortar Strength.—Mortar briquettes, cylinders or prisms, consisting of 1 part by weight of portland cement and 3 parts by weight (when approved by the engineer these proportions may be by volume, assuming 1 cu. ft. of cement to weigh 94 lb.) of fine aggregate, mixed and tested in accordance with the methods described in the "Standard Specifications and Tests for Portland Cement" shall show a tensile or compressive strength at the age of 7 and 28 days not less than that of 1:3 standard Ottawa sand mortar of the same consistency made with the same cement.

In testing aggregates, care should be exercised to avoid the removal of any coating on the grains which may affect the strength; bank sand should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample and the weight of the sand used in the test corrected for the moisture content.

If the grading of a sand is uniform and it contains no organic matter, nor an excess of loam, the compressive strength ratio to standard sand will be greater than 100 per cent and it will be satisfactory for use in any concrete. It does not follow, however, that sands which give certain mortar strengths will give, when mixed with coarse aggregate, similar concrete strength ratios. Though a good deal of importance has always been attached to the mortar test, a sand generally should not be discarded on the basis of its mortar strength, if by adopting with it certain proportions of cement, coarse aggregate and water a suitable concrete of satisfactory strength can be obtained.

177. Local Specifications.—Often economic considerations and local conditions are such that an engineer is confined to the use of a single available fine and a single coarse aggregate and restricted in the details of his specifications unless he is willing to pay an excessive cost. Thus in Washington, D. C., the complete aggregate specifications may be:

178. Sand.—The sand shall be equal to what is known locally as best well-graded Potomac River concrete sand. It shall be clean and free from injurious soft particles or organic matter.

179. Gravel.—The gravel shall be equal to what is known locally as best well-graded Potomac River $4\frac{1}{2}$ -in. washed gravel. It shall be clean and free from objectionable matter.

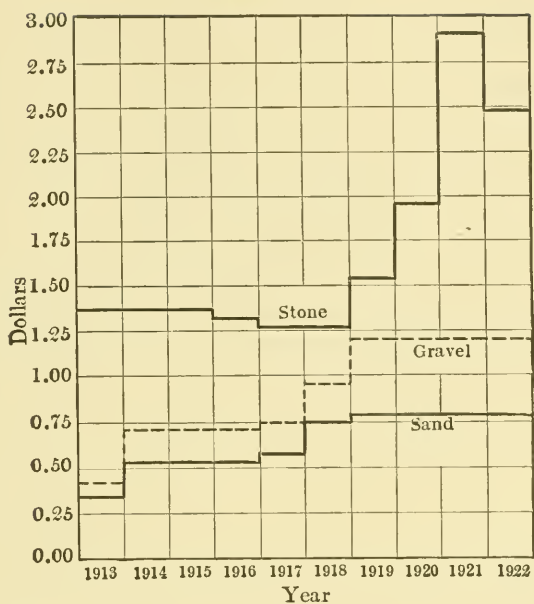


FIG. 86.—Cost of sand, stone and gravel, in the District of Columbia.

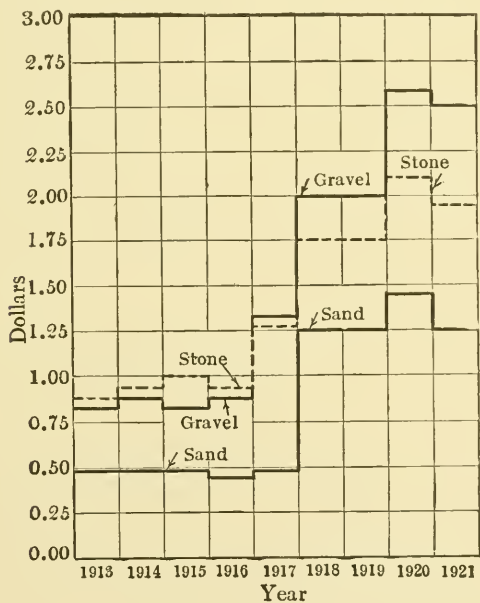


FIG. 87.—Cost of sand, stone and gravel in New York City.

In this case it is necessary to take the available aggregates, combine them in such proportions and with such quantities of cement and water as to give workable concretes, satisfactory for the work in hand, of the required strength and at minimum cost. The requirements of modern traffic emphasize the necessity for good concrete, rather than a straining after the highest theoretical type of aggregate. The wearing resistance of a concrete road is much more dependent on the quality of the concrete than on the quality of the aggregate.

180. Cost of Aggregates.—Figures 86 and 87 illustrate how greatly the cost of aggregates depend upon local conditions.

CHAPTER IX

TESTS OF CONCRETE

181. Scope.—Compression tests of concrete are the best of all guides in designing mixtures for pavements. Primary importance, at times has been attached to wear tests of concrete but these throw little light upon the probable length of service which will be rendered by pavements; none in the case of a concrete base, and even with wearing surfaces, where pavements fail there is seldom or never evidence of detrimental wear or abrasion. Such failure is always due to the concrete breaking, spalling or crumbling away. Furthermore, the wearing qualities if considered of importance, are satisfactorily covered by the compression test, for investigations of wear at the Lewis Institute show that the factors which produce concrete of high compressive strength produce low wear; the greater the strength, the greater the resistance to abrasion.

As with cement tests, so with those of concrete, results vary in different laboratories; and even in a single laboratory using the same trained operators day after day, different results must be expected. At least three test pieces should be molded for each determination and the average taken. Of test specimens designed to stand 3,000-lb. compression it is not unusual to have the weakest break at 2,500 lb. and the strongest at 3,500 lb. per square inch.

In the following paragraphs, extracts from the American Society for Test Materials Tentative methods, C39-21T, are given in fine print.

182. Compression Tests.—These methods are intended to cover compression tests of concrete made in a laboratory where accurate control of quantities of materials and test conditions is possible. They are designed to apply primarily to hand-mixed concrete. These methods may be used with slight modification in making tests of concrete for wearing resistance, bond between concrete and steel, impermeability, etc. The investigation of machine-mixed concrete will require certain obvious changes in the method.

183. Sampling for Preliminary Tests.—Representative samples of all concrete materials shall be secured for preliminary tests prior to the proportioning and mixing of the concrete. Cement test samples may be made up of a small quantity from each sack used in the concrete tests. Test samples of aggregates may be taken from larger lots by quartering.

184. Preparation of Materials.—Materials shall be brought to room temperatures (65 to 75°F.) before beginning tests. Cement shall be stored in a dry place; preferably in covered metal cans. The cement shall be thoroughly mixed in advance, in order that the sample may be uniform throughout the tests. It shall be sifted through a No. 16 sieve and all lumps rejected. Aggregates shall be in a room-dry condition when used in concrete tests. In general, aggregates should be separated on the No. 4, $\frac{3}{8}$ -in. and $1\frac{1}{2}$ -in. sieves and recombined to the average original sieve analysis for each batch. Fine aggregate should be separated into different sizes also, in cases where unusual gradings are being studied.

185. Cement Tests.—Cement shall be subjected to test, using the methods described in the Standard Specifications and Tests for Portland Cement.

186. Fine Aggregate Tests.—Fine aggregates (passing through a No. 4 sieve) shall be subjected, when required to the following tests:

- (a) Sieve analysis test.
- (b) Test for organic impurities (natural sand only).
- (c) Test for quantity of silt, clay or dust.
- (d) Test for unit weight.
- (e) Strength test of 1:3 mortar by weight at 7 and 28 days in comparison with standard sand mortar.

187. Coarse Aggregate Tests.—Coarse aggregates (retained on a No. 4 sieve) shall be subjected when required to the following tests:

- (a) Sieve analysis test.
- (b) Test for quantity of silt, clay or dust.
- (c) Test for unit weight.

188. Mixed Aggregate Tests.—The unit weight of mixed fine and coarse aggregates as used in concrete tests shall be determined.

189. Proportioning for Tests.—The quantities of each size of aggregate to be used in each batch shall be determined on the basis of the sieve analysis and the unit weight of the mixed aggregate. The exact quantities of cement and of each size of aggregate for each batch shall be determined by weight. The quantity of water for each batch shall be accurately measured. The quantities of materials may be expressed as (a) 1 volume of cement to—volumes of total aggregate mixed as used, or (b) 1 volume of cement,—volumes fine aggregate, and—volumes of coarse aggregate.

NOTE.—It is impracticable to give a general method for proportioning concrete for experimental purposes; the details will necessarily vary

widely with the purpose for which the tests are made. The following procedure is suggested for specific cases:

(a) Vary the cement content by 10 per cent intervals above and below assumed quantity.

(b) Vary the proportions of fine to coarse aggregate, measured separately, at intervals of 10 per cent.

(c) Vary the quantity of mixing water by intervals of 10 per cent.

190. Size of Test Pieces.—Compression tests of concrete shall be made on cylinders of a diameter equal to one-half the length. The standard shall be 6 by 12-in. cylinders where the coarse aggregate does not exceed 2 in. in size; for aggregates larger than 2 in., 8 by 16-in. cylinders shall be used; 2 by 4-in. cylinders may be used for mixtures without coarse aggregate.

The 6 by 12-in. cylinders are better than 8 by 16-in. for ordinary use because they are lighter weight and require smaller quantities of material. Tests made under the auspices of an American Society for Testing Materials committee showed that within the limitations indicated, the size of the specimen has practically no effect upon the strength provided the ratio of height to diameter is the same.

If tests are made on specimens having other ratios of height to diameter than 2:1, correction must be made for this difference in shape of specimen. With cubes it was found that the strength of the standard cylinder would be approximated by multiplying the cube strength by 0.73. Specimens with a height one-half the diameter, were about 50 per cent stronger than the cube. To convert to standard cylinder strength, that of the half cube must be multiplied by 0.48.

191. Mixing Concrete.—(a) Concrete shall be mixed by hand in batches of such size as to leave a small quantity of concrete after molding a single test piece. The batch shall preferably be mixed in a shallow galvanized steel pan with a 10-in. bricklayer's trowel which has been blunted by cutting off about 2½ in. of the point, as follows:

(b) The cement and fine aggregate shall be mixed dry until the mixture is homogeneous in color.

(c) The coarse aggregate shall be added and mixed dry.

(d) Sufficient water shall be added to produce concrete of the required workability.

NOTE.—Concrete tests should be made on plastic mixtures. It is of the utmost importance that a uniform degree of workability be secured in tests involving comparisons of different materials and methods.

(e) The whole shall be mixed thoroughly until the entire mass is homogeneous in appearance.

192. Consistency.—The consistency of concrete mixtures, which is also often called workability or plasticity, may be measured immediately after mixing by one of the following methods: (The Slump Test is American Society for Testing Materials Tentative method, D138-22T and the Flow Test is extracted from C39-21T.)

193. Slump Test.—(1) This test covers the method to be used both in the laboratory and in the field for determining consistency of concrete¹ to be used for concrete pavements or for concrete base for pavements.

194. Apparatus.—(2) The test specimen shall be formed in a mold of No. 16 gage galvanized metal in the form of the lateral surface of the frustum of a cone with the base 8 in. in diameter, the upper surface 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles.

195. Sample.—(3) When the test is made at the mixer, the sample shall be taken from the pile of concrete immediately after the entire batch has been discharged. When testing concrete that has been hauled from a central mixing plant, the sample shall be taken from the concrete immediately after it has been dumped on the sub-grade.

196. Procedure.—(4) The mold shall be placed on a flat, non-absorbent surface, such as a smooth plank or a slab of concrete, and the operator shall hold the form firmly in place, while it is being filled, by standing on the foot pieces. The mold shall be filled to about one-fourth of its height with the concrete which shall then be puddled, using 20 to 30 strokes of a $\frac{1}{2}$ -in. rod pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then be removed by being raised vertically, and at exactly 3 min. after being filled. The molded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

(5) The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump.

Slump = 12—inches of height after subsidence

197. Flow Test.—The flow test is made by placing a metal form in the shape of a frustum of a cone $6\frac{3}{4}$ in. in top diameter, 10 in. in bottom diameter, 5 in. deep on the table of the flow apparatus. The fresh concrete shall be placed in the mold in two layers. Each layer shall be

¹ This test is not considered applicable when there is a considerable amount of coarse aggregate over 2 in. in size in the concrete. The committee is now working on a method suitable for determining the consistency of concrete using aggregate over 2 in. in size.

puddled and finished as later described for molding test pieces. Immediately after molding the form shall be removed by a steady upward pull; the specimen raised $\frac{1}{2}$ in. and dropped 15 times in about 6 sec. by means of a suitable cam and crank. The spread of the fresh concrete due to this treatment as compared with the original bottom diameter of the cone, expressed as a percentage, is the "flow."

Six seconds is an awkwardly short time for 15 operations. While the time should perhaps depend somewhat upon the effectiveness of the equipment it simplifies matters if the table is raised and lowered once per second and there appears to be no good reason for not adopting such a routine. At present it is largely a matter of choice whether the table should be dropped 15 times for each test or as many as 25 times. Twenty is certainly better than 15.

198. Application of Slump and Flow Test.—An understanding of the slump test may be had from Fig. 88, and the flow table is

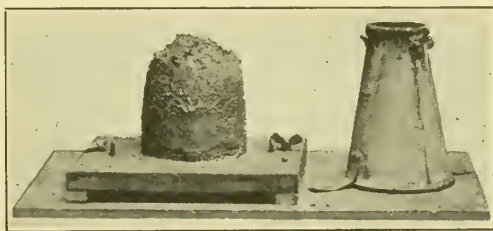


FIG. 88.—The slump test.

illustrated in Fig. 89. While it is interesting to compare slump and flow tests as is done in Fig. 90, neither can determine for the engineer how much water to use with any particular choice of aggregates, nor what consistency of concrete to use for any given class of work. These are matters that can be determined only by making actual use of trial mixtures; and in deciding upon his consistency it is the engineer's duty to use the minimum amount of water that will permit the concrete to be satisfactorily handled on the job. It is often difficult to hold a working gang down to the desired consistency, because it is easier to handle a soupy mixture than a stiff one, and therefore, it is necessary to have some means of showing the consistency desired; and therein, for the roadmaker lies the main field of application for either the slump test or the flow table. Aggregates peculiar to one locality

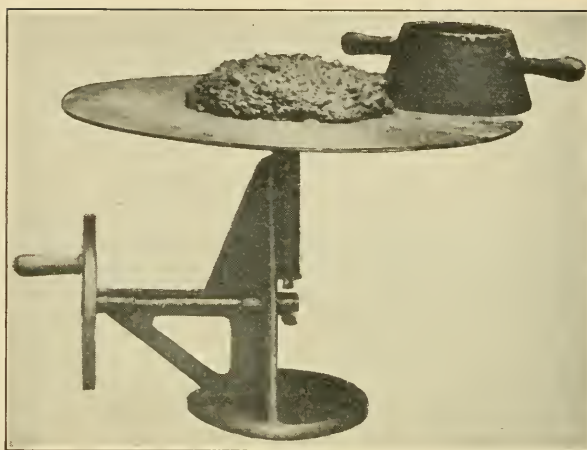


FIG. 89.—The flow table, as constructed by the U. S. Office of Public Roads.

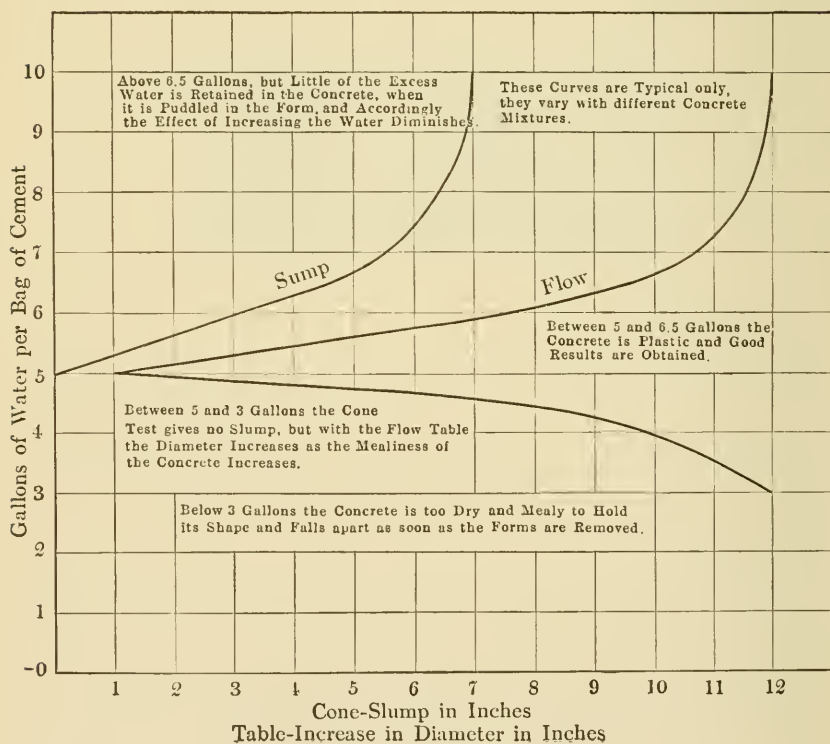


FIG. 90.

will not necessarily give the same consistency readings as those of another locality, though in making the pavement the two are handled under exactly like conditions. For any one group of materials, however, either the slump test or the flow table does enable the engineer to specify with sufficient exactness the consistency he desires and, further, permits him to show plainly beyond all room for argument whenever the gang on the job departs therefrom.

199. Forms for Cylindrical Test Pieces.—The forms shall preferably be of metal. Each form shall be provided with a machined metal base plate, and shall be oiled with a heavy mineral oil before using. Particular care shall be taken to obtain tight forms so that the mixing water will not escape during molding.

NOTE.—The best type of form consists of lengths of cold-drawn steel tubing, split along one element and closed by means of a circumferential band and bolt. Satisfactory forms can be made from lengths of steel water-pipe machined on the inside, from rolled metal plates, from galvanized steel, machined iron or steel castings. Paraffined cardboard molds will give good results under expert supervision.

200. Molding Test Pieces.—Concrete test pieces shall be molded by placing the fresh concrete in the form in layers 3 to 4 in. in thickness. Each layer shall be puddled with 25 strokes with a $\frac{5}{8}$ -in. round steel bar of a length 9 in. greater than the length of the mold, pointed at the lower end. After the top layer has been puddled, the surplus concrete shall be cleaned off with a trowel, and the mold covered with a machined metal plate or a piece of plate glass at least $\frac{1}{4}$ in. thick, which will be used later in capping the test piece.

201. Capping Cylinders.—Two to four hours after molding, the test pieces shall be capped with a thin layer of stiff neat cement paste in order that the cylinders may present a smooth end for loading. The cap shall be formed by means of a machined metal plate or a piece of plate glass of suitable size, at least $\frac{1}{4}$ in. thick, worked down on the fresh cement paste until it rests on the top of the cylinder form. The cement for capping shall be mixed to a stiff paste before beginning to mix the concrete; in this way the tendency of the cap to shrink will be largely eliminated. The adhesion of the concrete to the metal base plate and the glass can be largely eliminated by oiling the cover plate and by inserting a sheet of paraffined tissue paper.

202. Curing Test Pieces.—Concrete test pieces shall be removed from the forms 20 to 48 hr. after molding, marked, weighed and stored in damp sand, under damp cloths or in a moist chamber until the date of test. The temperature of the curing room should not fall outside the range of 60 to 75°F.

As illustrated by Fig. 91, moisture is necessary in order that portland cement may properly cure and gain a reasonable portion of its full strength in minimum time. Moisture is necessary also if uniform results are to be obtained. If the specimens were permitted to dry out in the usual room atmosphere, erratic gains in strength would result.

203. Age at Test.—Tests shall be made at the age of 7 and 28 days; ages of 3 months and 1 year are recommended if longer time tests are required.

Referring to the curve "Concrete Stored in Wet Sand," Fig. 91, it is seen that at 7 days specimens are increasing in strength

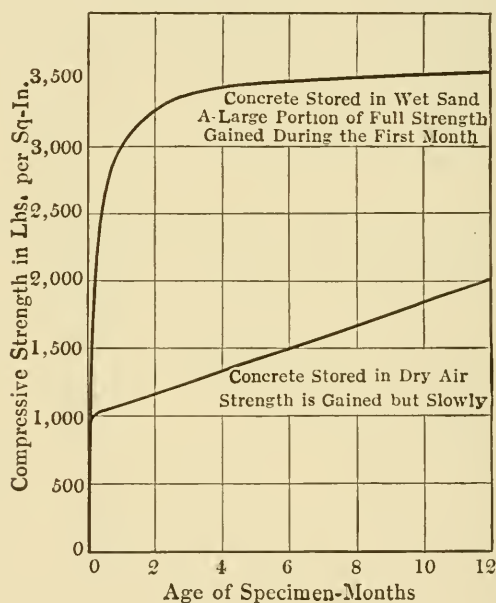


FIG. 91.—Typical curves showing the increase of strength with age, and the effect of moisture.

at a maximum rate and, accordingly, any condition affecting the tests results in relatively large discrepancies at this age. Beyond an age of 28 days the specimens gain strength slowly; a few hours difference in the time of testing is then of relatively small importance; and so with other variables present in the making and handling of the specimens—the greater the age the less the effect. .

204. Sequence of Tests.—Three to five tests pieces should be made on different days in investigations in which accurate comparison are desired.

205. Preparation of Tests.—Compression tests shall be made immediately upon removal of the concrete test pieces from the curing room; that is, the test pieces shall be loaded in a damp condition. The length and average diameter of the test piece shall be measured in inches and hundredths; two diameters shall be measured at right angles near the mid-length. The test piece shall be weighed immediately before testing.

206. Method of Testing.—In general, only the ultimate compressive strength of the cylinders need be observed. The metal bearing plates of the testing machine shall be placed in contact with the ends of the test piece; cushioning materials shall not be used. An adjustable bearing block shall be used to transmit the load to the test piece. The bearing block shall be placed on top of the test piece in vertical testing machines. The diameter of the bearing block shall be approximately the same as that of the test piece. The upper section of the bearing block shall be kept in motion as the head of the testing machine is brought to a bearing on the test piece.

207. Application of Load.—The load shall be applied uniformly and without shock. The moving head of the testing machine should travel at the rate of about 0.05 in. per minute when the machine is running idle.

208. Record of Tests.—The total load indicated by the testing machine at failure of the test piece shall be recorded and the unit compressive strength calculated in pound per square inch, the area computed from the average diameter of the cylinder being used. The type of failure and appearance of the concrete shall be noted.

209. Weight of Concrete.—The weight of the concrete in pounds per cubic foot shall be determined from the weight of the specimens and their dimensions.

210. Density and Yield.—Density and yield of concrete when required shall be calculated from the unit volumes of the constituent materials and the volume of the concrete. Density is here understood to be the ratio of solids in the concrete to the total volume of the mass. Yield is the volume of concrete resulting from one volume of aggregate mixed as used.

211. Report of Tests.—The report of tests shall include the following:

- (a) The kind and origin of concrete materials.
- (b) Complete data on all tests of cement and aggregates.
- (c) A description of methods of making and testing the concrete, where methods deviate from the proposed standards.
- (d) The quantities of cement, aggregates and water in each batch.
- (e) The method of measuring workability or plasticity with "slump" or "flow" of concrete.

- (f) The quantity of water expressed as a ratio to volume of cement.
- (g) The age at test.
- (h) The size of test pieces.
- (i) The date of molding and testing each cylinder.
- (j) The compressive strength in pounds per square inch of each test piece and average of tests in a set.
- (k) A description of failure and appearance of concrete on each test piece.
- (l) The unit weight, density and yield of the concrete.

CHAPTER X

DESIGN OF CONCRETE MIXTURES

212. Quality of Concrete.—In the past, concrete mixtures have most often been arbitrarily specified without knowledge of the true strengths resulting from the use of any stated proportions of the given materials. The wide field in which it is used, and the ease with which it can be handled by unskilled persons and still give temporary superficial good appearance, has lead to much abuse of concrete as a paving material. Roadway concrete is subject to large temperature changes, alternate wetting and drying, and the pounding of traffic. Every effort is accordingly justified to produce a superior product; and in this spirit there has grown up on the part of those having to do with specification standardization a tendency to specify quality by “consistency” and “strength” rather than by proportions such as “1:2:3.” An example of such a proposed specification is as follows:

213. Quality.—The quality of concrete shall be expressed in terms of workability as determined by the slump test and of the compressive strength at 28 days as determined by concrete tests of the materials to be used. The proportions required to produce concrete having the strength specified shall be determined in advance of the mixing of the concrete.

214. Strength.—The concrete shall develop under the conditions specified in the preceding section, for the various parts of the work, the following strengths (the engineer to insert the strengths required).

In specifying “quality” it is contemplated that in order to obtain a desired strength the proportions to be used in concrete mixtures shall be determined either by the engineer or by the contractor or else in accordance with certain published tables; but in any case, upon failure to meet the specifications such changes are required to be made in the materials, proportions or mixing as may be necessary to secure concrete of the desired strength.

Contractors feel that this strength requirement places an undue burden upon them. They believe that the present state of the art is such that a specified strength cannot be guaranteed and

that it is the duty of the engineer to take the chances involved in attempting to produce a given strength. Concrete is a job-made material and results obtained depend upon a great number of variable factors. Even under favorable laboratory conditions the strength of cylinders taken from a single mixture varies greatly and also different laboratories testing identical materials may obtain widely different results. The main problem of proportioning is to coordinate laboratory and field control so as to develop a workable practice.

The contractor's interests can be guarded, if it is desired to specify concrete of a given strength, by payment on a sliding scale, for instance dependent upon the amount of cement used per square yard of pavement. If aggregates are used that are well known to the engineer, he may, by stipulating certain proportions for his work, obtain concrete of satisfactory strength. On the other hand, if the contractor imports aggregates which are entirely new to the engineer, something more than an arbitrary requirement as to proportions is necessary. Any plan that helps to insure concrete of a predetermined strength and quality is a step in the right direction. If concrete is placed in a roadway and then 28 days later a compression test shows that the specification as to "quality" is not fulfilled a difficult situation develops. For many years investigators have searched for some measure that could be applied to materials prior to actually making concrete of them, and which would foretell strength.

215. Fineness Modulus.—The fineness modulus method of measuring aggregates in order to determine how much cement and water to use, in order to obtain specified strengths, is set forth by Professor Abrams in *Bulletin 1*, April, 1919, of the Structural Materials Research Laboratory, Lewis Institute. The scheme is based upon the cumulative plot of the mechanical analysis of aggregates. In Fig. 92, using a logarithmic horizontal scale, the curve represents an aggregate with the per cent coarser than each sieve plotted against mesh openings in millimeters. Assuming each of the vertical rectangles to have a width of $\frac{1}{100}$ unit, their summation, giving the area beneath the curve, amounts to 2.79, the fineness modulus of the aggregate. The summation of the horizontal rectangles amounts to the same, but in addition is equivalent to taking the ordinary sieve analysis and weighting the per cent retained on each sieve, after having passed through the next larger, in accordance with an arithmet-

ical progression, the common difference being $\frac{1}{100}$ as the sieve sizes increase (that passing the smallest sieve is weighted zero). It is evident as illustrated by the summation of the horizontal rectangles that the fineness modulus scheme is an empirical one which arbitrarily gives more weight to the larger particles making

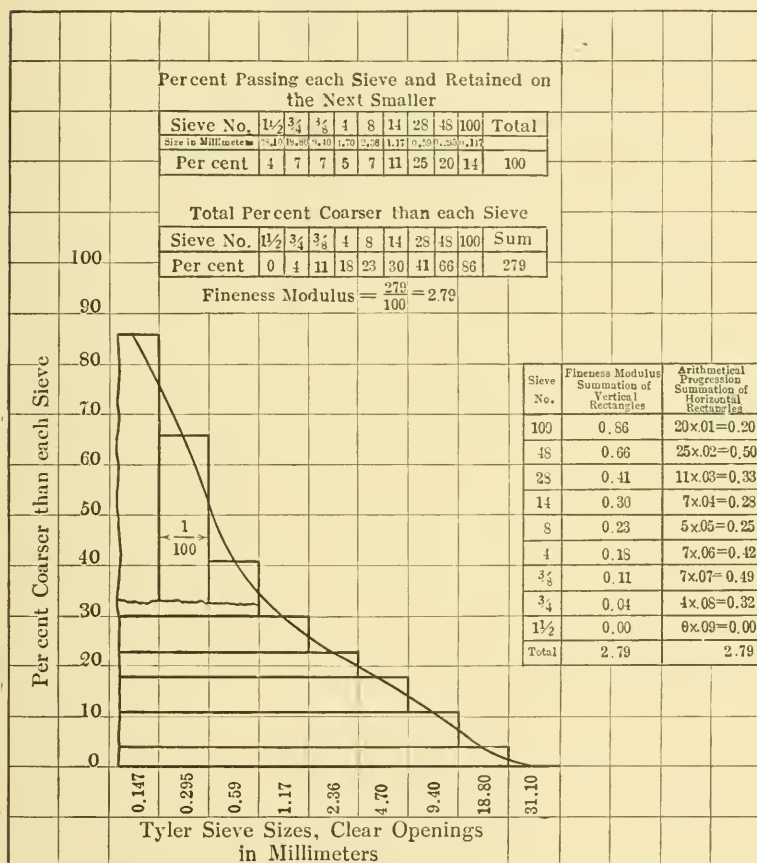


FIG. 92.—Adding up the two parallel columns shows that, since the sum of the horizontal rectangles gives the same amount as the fineness modulus, the latter is equivalent to weighting the per cent of aggregate retained on each sieve in accordance with an arithmetical progression, the common difference being $\frac{1}{100}$ as the sieve sizes increase.

up aggregates. Accordingly, there must remain a doubt as to the universal applicability of the method to the proportioning of specific mixtures.

216. Surface Area.—In the 1918 American Society for Testing Materials Proceedings, L. N. Edwards describes "Proportioning the Materials of Mortars and Concretes by Surface Areas of Aggregates." Since that time Young and McCarthy of the Hydro-electric Power Commission of Ontario have used the surface area method as an aid in work carried on by the Commission. In computing surface areas, the grains of mineral aggregate are assumed to be either cubes, spheres or other shapes, in formulae relative to which a mean diameter and certain constants enter. When a granulometric analysis has been made, the various mesh sizes are assumed to be the mean diameters. The number of grains in a net volume of matter passing through any one sieve depends upon the volume of each grain, that is, the number varies inversely as the cube of the mesh diameter. The area of each grain varies as the square, and therefore the total areas of the volumes through the sieves vary inversely as the sieve diameters. Then, if each sieve mesh has openings one-half those of the next larger sieve, the weight attached by the surface area scheme to the volume through each sieve would be as in Table IX, where comparison is made with the fineness modulus scheme.

TABLE IX.—COMPARISON OF TWO METHODS

Sieve number	Per cent passing and retained on the next smaller	Weighted by arithmetical progression	Weighted by geometrical progression
		Fineness modulus	Surface area
100	14	.....	$14 \times 2.56 = 35.84$
48	20	$20 \times 0.01 = 0.20$	$20 \times 1.28 = 25.60$
28	25	$25 \times 0.02 = 0.50$	$25 \times 0.64 = 16.00$
14	11	$11 \times 0.03 = 0.33$	$11 \times 0.32 = 3.52$
8	7	$7 \times 0.04 = 0.28$	$7 \times 0.16 = 1.12$
4	5	$5 \times 0.05 = 0.25$	$5 \times 0.08 = 0.40$
$\frac{3}{8}$	7	$7 \times 0.06 = 0.42$	$7 \times 0.04 = 0.28$
$\frac{3}{4}$	7	$7 \times 0.07 = 0.49$	$7 \times 0.02 = 0.14$
$1\frac{1}{2}$	4	$4 \times 0.08 = 0.32$	$4 \times 0.01 = 0.04$
		Fineness modulus = 2.79	Surface area factor = 82.94

The numerical value of the surface area depends upon the units and constants assumed in its computation. It may, however,

be represented by a factor as illustrated in the table. The volume through each sieve is weighted in accordance with a geometrical progression, the first term, representing the $1\frac{1}{2}$ -in. sieve, being 0.01, and the common ratio being 2 as the sieves become smaller, until a weight of 2.56 is attached to the No. 100 sieve. The fineness modulus method gives no weight to the material passing through the No. 100 sieve while the surface area method attaches maximum weight to this material. There is no relationship between fineness modulus and surface area except that, as the former increases the latter decreases. When the one is a maximum the other is a minimum. Thus we find that in evaluating an aggregate, though the two methods might interpret its cement and water requirements equally, the one would give the aggregate a high numerical value and the other a low value. Each is an empirical method and neither is general enough in application to produce a guaranteed strength for concrete.

217. Methods by Voids.—For many years (Feret published the results of his studies in 1892) engineers have tried to establish rules for proportioning concrete on a relationship between cement, voids and strength. In general the void method asserts that the densest and strongest concrete that can be made with any proportion of cement and any combination of aggregate is that in which the cement paste fills the voids of the sand and the resulting mortar fills the voids in the coarse aggregate. From 1904 to 1907, W. B. Fuller (*Trans. A. S. C. E.*, 1907) developed his maximum density curves which call for artificial grading of aggregates in accordance with specified sieve analyses in order to obtain concrete of maximum density. Very recently Prof. G. M. Williams (*Journal of the Engineering Institute of Canada*, 1921) carried out tests giving results in which the highest strength was not found for concrete having maximum density. He states instead, that, considering material from any one source, the combination of dry sand and coarse aggregate having the greatest unit weight generally produced the strongest concrete; but he proposed no method of predicting the strength that would result when using given quantities of cement and aggregate. Professor Talbot shows (*A. S. T. M. Proceedings*, 1921) a relationship between strength and the space occupied by cement paste in the wet mixture. As a means of predicting either of these two elements he proposes to measure the space occupied by cement

paste in mixtures made without the coarse aggregate; that is, the fine aggregate alone is used.

Though the studies that have been made by the several investigators whose methods have been outlined, and by many others, have been a material step forward, further research and experience are necessary. Schemes based either on granulometric or void-

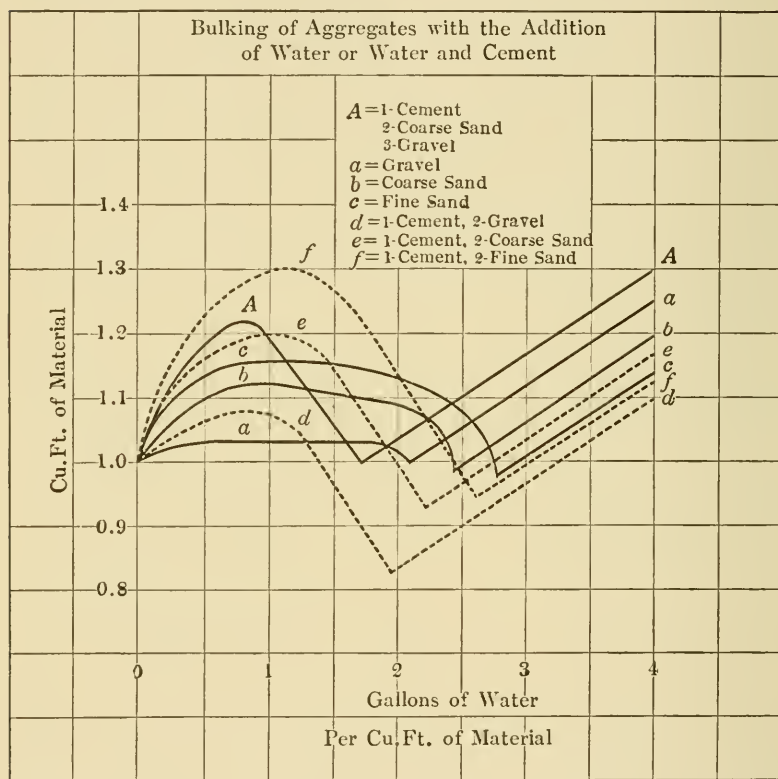


FIG. 93.— Mixtures puddled in 3-in. layers with a steel rod. With the addition of water, volumes first increase then decrease. The points of minimum volume with cement mixtures give maximum strengths. These points represent slumps of about 1 in. The addition of water after the point of minimum volume is reached increases the bulk in amount equal to the volume of the added water.

age measurements, either of dry aggregates alone or of dry aggregates plus cement, all fail to take into consideration changes in volume caused by the addition of water, as illustrated in Fig. 93, and therein they fail as indices of concrete strengths. Usually the choice of aggregates is a simple matter because restricted to

those locally available. The main problem is to combine the available sand and coarse aggregate in such manner as to give the best concrete for the least money and satisfactory for the work in hand; the process of doing which will be illustrated in the following paragraphs.

218. Measuring Ingredients.—First of all, it is necessary to adopt such methods of measuring ingredients for concrete as will insure compliance with the designs of the engineer. For the laboratory American Society for Testing Material methods are followed. For field work the 1921 progress report of the Joint Committee representing the American Society for Testing Material and several other engineering and commercial bodies proposed:

219. Unit of Measure.—The unit of measure shall be the cubic foot. Ninety-four pounds (one bag or $\frac{1}{4}$ bbl.) of portland cement shall be considered as 1 cu. ft.

220. Method of Measuring.—Each of the constituent materials shall be measured separately by volume (weight). The method of measurement shall be such as to secure the specified proportions in each batch. If volume measurement is used, the fine aggregate and the coarse aggregate shall be measured loose as thrown into the measuring device. The water shall be measured by an automatic device that will insure the same quantity in successive batches.

221. Measuring Aggregates.—Referring to Fig. 93, it may be understood that the presence of moisture influences the measuring of aggregates, not so much in the case of coarse materials, but to a large extent in the case of sands. Assume that on account of rain, or the receipt of sand fresh from the dredge, it has a bulk 20 per cent greater than when dry. Then 1 cu. ft. of sand actually measures 1.2 cu. ft. and if a 2-cu. ft. barrow is struck off level it will contain but $1\frac{2}{3}$ cu. ft. of sand, and instead of a 1:2:3 mixture, for instance, a proportion of $1:1\frac{2}{3}:3$ would be obtained. This generally means that more cement per square yard of pavement is used than was estimated for and on that account it is on the side of safety as far as strength is concerned; but the decrease in the sand might give a mixture not quite as easily brought to a surface finish as that contemplated by the original design. In the tests described in subsequent paragraphs aggregates were measured at room-dry conditions, the moisture present being less than $\frac{1}{2}$ of 1 per cent, by weight and therefore, immaterial.

When a central proportioning or mixing plant is used with bins and measuring boxes, no trouble need be experienced in obtaining all necessary accuracy in measuring aggregates. Wheelbarrow charging of mixers, however, is far from being obsolete. If the use of barrows is not closely supervised leaner concrete than specified invariably results. Specifications should require barrows to have sides not more than 2 ft. apart and to be of such capacity that when struck off with templates, as



FIG. 94.—Aggregate when charged by wheelbarrows should be struck off evenly by means of templates as illustrated.

illustrated in Fig. 94, they will contain the exact volume required. When barrows are required to carry a three fourth load or a heaping load very indefinite measurement results.

222. Water-cement Ratio.—Professor Abrams in his *Bulletin 1*, shows a relation between compressive strength and water content for 28-day tests of 6 by 12-cylinders. Mixes from 1:15, to neat cement were used; each mix was made up of aggregates ranging in size from 14-mesh sand up to $1\frac{1}{2}$ -in. gravel; a wide range in consistencies was used for all mixes and gradings. The water content was expressed as a ratio to the volume of cement. Carrying out this scheme with various combinations of District

of Columbia aggregates and plotting compressive strength against gallons of water per bag of cement a smooth curve was obtained, Fig. 95, which is practically identical with that of Professor Abrams.

With this curve and by simply noting the gallons of water used for each bag of cement (based on dry aggregates) an approximation may be obtained of the strength that will result at 28 days. Specimens of concrete mixed in proportions and of consistency suitable for roadwork will generally plot within 500 lb. of the curve; and the method is therefore seen, in view of the variable

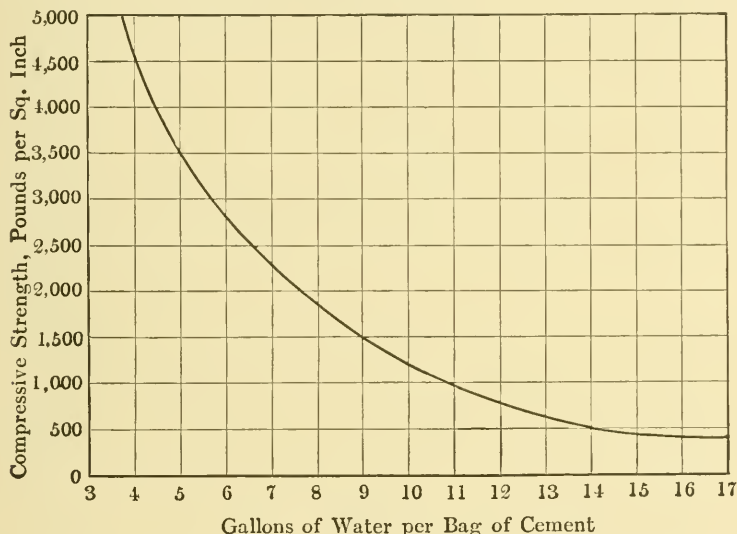


FIG. 95.—Relation between compressive strength of 28 days concrete and the water used per unit of cement.

results obtained in the compression test itself, to be a fairly satisfactory scheme for estimating strength. For aggregate combinations containing few or no small particles (of such coarse grading as to be unfit for pavement construction) the curve cannot be used. For these aggregates it may be found that the same amount of water per bag of cement is required for a 1:4 mix as for a 1:10 mix though the latter may test but half as strong as the former.

When unreasonably dry mixtures are used the curve is not applicable, which may be explained by reference to Fig. 96, in which the lower curve is a copy of that previously shown as Curve A in Fig. 93. As the amount of water is decreased below $1\frac{3}{4}$ gal.

down to about 1 gal. (for this particular mixture) the concrete is less and less plastic and accordingly the swelling effect is increasing. This leads to excessive voids and thus between $1\frac{3}{4}$ and 1 gal., decreasing the water is accompanied by decrease in strength; which is the reverse of what is indicated by the Water-cement Curve, Fig. 95. Further decrease in the amount of water, while not providing sufficient moisture to give maximum bulking

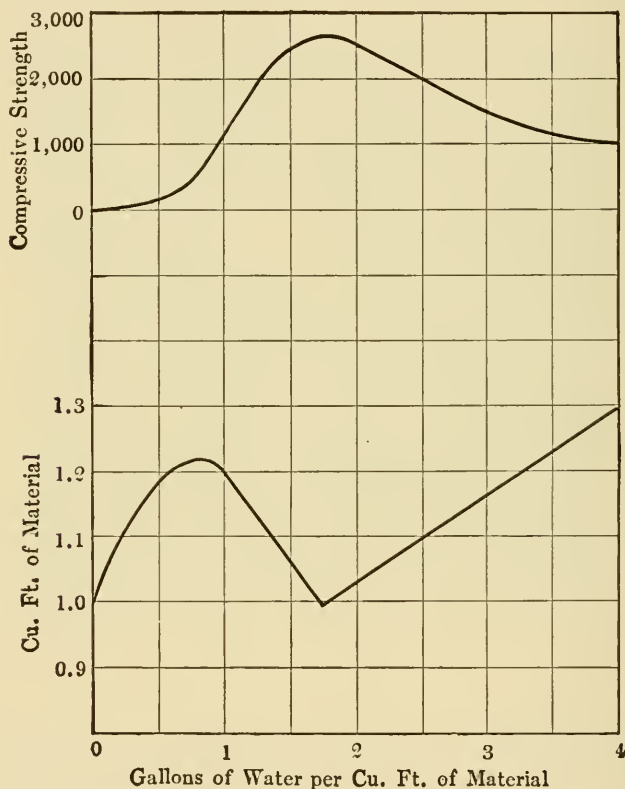


FIG. 96.—Comparison of the "strength" curve with the "bulking" curve of a 1-2-3 mixture. Maximum strength corresponds to minimum bulk.

effect also does not provide sufficient moisture for properly molding the specimens and the strength falls away rapidly to zero.

Using between $1\frac{1}{2}$ and 2 gal. of water per cubic foot of material with the mixture in question gives consistencies close to those generally used for pavement construction, the strength within these limits is fairly uniform and the maximum corresponds to

the point of least volume on the lower curve. When additional water is added it rises to the surface when the concrete is tamped; and further addition, if the concrete is well puddled, simply increases the volume by an amount equal to that of the water added, which is indicated by the straight portion of the lower curve. Strength values obtained with excessively wet mixtures are erratic, results depending upon how the concrete is handled. If all the excessive water is not brought to the surface by puddling, it, being more than required for hydration of the cement, leaves upon evaporation, many voids in the concrete. Generally, a good deal of the excessive water is lost in mixing and transporting the concrete; and this wasted water always carries away much valuable cement. While to use more water than necessary to produce a usable consistency wastes cement, reduces strength and should not be countenanced, it should be borne in mind that to use too little water is likewise inexcusable. Too dry concrete is a common fault with base construction from a central plant. Being dry it dumps readily from trucks, and having more bulk than a wetter mixture, a cubic yard makes more pavement for the contractor.

Referring once more to the water-cement curve, it is desired to emphasize that within its limitations it supplies a direct and easy method of estimating the strength of concrete. Combining with it aggregate measurements on the fineness modulus or other similar lines merely complicates the procedure and decreases the accuracy of the findings. The number of gallons of water used per bag of cement serves as an index of strength because this ratio measures the cement-paste carrying capacities of the different combinations of aggregates. This carrying capacity depends, first, upon the total volume of voids in the aggregate and then upon the extent to which this volume is increased when the cement-paste is placed around and between the grains comprising the aggregate. With fine aggregates this increase in volume is greater than with coarser ones; and, therefore, for given consistencies the finer ones require the greater amounts of water, the cement paste is diluted to a greater extent and for fixed quantities of cement, concretes made with fine aggregates accordingly develop less strength than those made with coarser aggregates. Also, the volume of space occupied by the cement, using any one set of aggregates and a fixed quantity of cement, increases (for wet mixtures ordinarily used) as the water is increased, which

means that strength decreases as the water is increased. A given ratio of water to cement corresponds to a fixed strength. The addition of excess water in order to obtain a desired consistency or workability reduces strength and therefore, to obtain the desired consistency, maintaining strength constant, it is necessary to increase both cement and water. In other words, the basic element of the theory is that for given strength, the water-cement ratio must be kept constant.

223. Cement-space Ratio.—Using the same combinations of aggregates as have just been discussed in relation to the water-

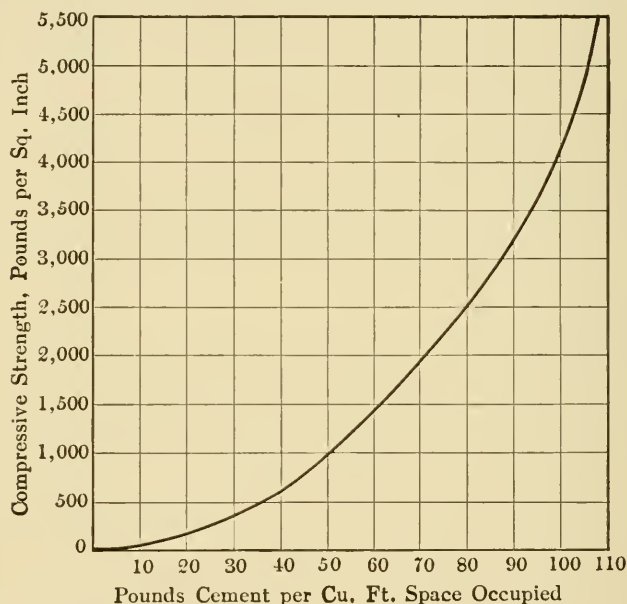


FIG. 97.—Relation between compressive strength of 28-day concrete and the space occupied by the cement.

cement ratio, but plating compressive strength against pounds of cement per cubic foot of space occupied by the cement, a curve was obtained, Fig. 97, differing from a straight line obtained by Professor Talbot, in that the curve begins at zero cement for zero strength and approximates 110 lb. of cement per cubic foot of space for neat cement giving a strength of between 7,000 and 8,000 lb. per square inch. These are two points neglected by the Talbot straight line. When there is neither time nor facilities for the compression test, this cement-space curve may be used for estimating strength just as the water-cement curve,

and with more accuracy, though to figure out the pounds of cement per cubic foot of space is a more laborious matter than to note simply the gallons of water used per bag of cement.

To obtain the cement-space ratio it is necessary to know, first of all, the specific gravities of the aggregates. Then with any proportions, for instance, 1 cement:2 sand:3 gravel, measure sufficient quantities to produce about a cubic foot of concrete. Weigh the sand and the gravel, and, using their specific gravities, compute their absolute volumes. Mix the concrete and puddle it into a measure. Subtracting from the volume of the concrete the absolute volume of the aggregate gives the space which is occupied by the cement paste, from which may be computed the pounds of cement per cubic foot of space occupied.

The cement-space curve holds for dry mixtures (to the point where they can no longer be molded for the compression test) as well as for normal ones because, as the mixtures swell on account of too little water, the space occupied by the cement increases, and therefore decreases in strength caused by insufficient water are fairly well represented. Also in the case of very wet mixtures where the excess water leads to voids in the concrete the decreases in strength are taken care of by the increase in space occupied by the cement. When, however, so much water is used that it runs away carrying cement with it no scheme can be used for estimating strength since no one knows how much cement is wasted.

The cement-space curve and also the water-cement curve are general in character and may be applied irrespective of the nature of the aggregates or of the consistency of the concrete. For road work, however, the consistency may be confined to narrow limits and in any one locality there are but few varieties of aggregates available. With these restrictions in mind it is possible to work out further data, and for these specific cases to show information in greater detail.

224. Aggregate Denseness.—When a sand is combined with a coarse aggregate in proportions ranging from zero sand with 100 parts of coarse aggregate, to 100 parts of sand with zero coarse, a curve of denseness may be platted, with, at its vertex, the combination having minimum voidage and maximum weight per cubic foot. Two such curves are shown in Fig. 98. Curve 1 illustrates a $1\frac{1}{2}$ -in. gravel combined with a fine sand and Curve 2, the same gravel combined with a coarse sand. These

two curves illustrate that, starting with any two aggregates as, for example, No. 4, $1\frac{1}{2}$ -in. gravel and 0-No. 4 sand, certain fundamental rules may be stated:

(a) If finer sand in increasing amounts is substituted for some of the given sand, the peak of the curve moves toward larger and larger proportions of the coarse aggregate.

(b) Substituting coarser sand for some of the 0-No. 4 has an effect the reverse of substituting fine sand.

(c) If finer gravel in increasing amounts is substituted for some of the given gravel, the peak of the curve moves toward larger and larger proportions of sand.

(d) Substituting coarser gravel for some of the No. 4, $1\frac{1}{2}$ in. has an effect the reverse of substituting fine gravel.

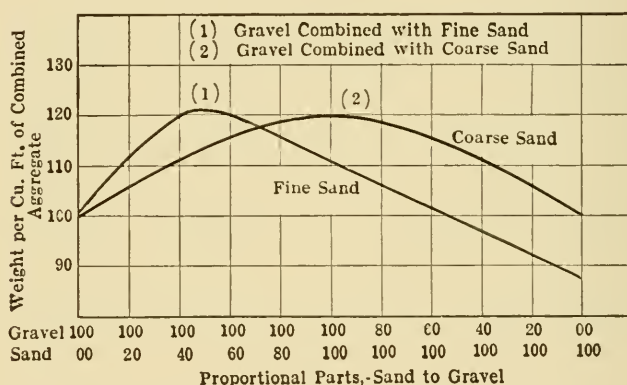


FIG. 98.—Curves of denseness.

It has been held by many, that maximum concrete strength is obtained with any given aggregates when they are combined so as to give maximum denseness. A factor in favor of this hypothesis is that, for given proportions of sand and coarse aggregate, more cement is used per cubic foot of combination for the denser mixtures than for those having larger percentages of voids. This may be explained by taking as an example 1 part cement to 4 of aggregate; using sand and gravel, each weighing 100 lb. per cubic foot. If, in the combination, the 4 parts of aggregate comprise gravel only, the sand being equal to zero, there would be used $\frac{1}{4}$ bag, or 23.5 lb. of cement, per cubic foot of aggregate. If the 4 parts of aggregate were in the proportion 100 gravel to 100 sand (2:2) and weighed 120 lb. per cubic foot as shown by

Curve 2, Fig. 98, then $1\frac{20}{400}$ bag, or 28 lb. of cement per cubic foot of aggregate would be used.

In opposition to the hypothesis aforementioned, however, there is another factor which, regardless of the denseness, tends to give stronger concrete as the coarseness of the aggregate is increased. The coarser the aggregate the less water necessary, for concrete of given consistency, and, accordingly there is less space to be occupied by the cement. Referring to Curve 2, a 40:100 combination (2:5) has the same denseness as a 100:40 combination (5:2), each weighing 111 lb. per cubic foot. In a 1 cement : 7 aggregate mixture, $1\frac{11}{400}$ bag or 14.9 lb. of cement would be used per cubic foot of aggregate, for either the 2:5 or 5:2 combination. Actual trial shows that for the former, based on a consistency suitable for pavements, 1.24 gal. of water are necessary, and for the latter, 1.73 gal. per cubic foot of combined aggregate. The extra water required for the finer aggregate, that is, the 5:2 combination, holds the particles apart and the resulting volume of concrete measures 10 per cent more than that of a 2:5 combination. In the 5:2 concrete the 14.9 lb. of cement occupies 0.30 cu. ft. of space compared to 0.22 cu. ft. for the 2:5.

The data relative to these two mixtures give for the 2:5 combination 68 lb. of cement per cubic foot of space occupied and 7.8 gal. of water per bag of cement; and for the 5:2 combination, 49 lb. of cement per cubic foot of space occupied and 10.9 gal. of water per bag of cement. Thus when the strength of concrete is plotted against proportional parts, sand to gravel, in a manner similar to that used in Fig. 98, the peaks of the resulting curves fall toward larger proportions of gravel than do the peaks of the curves of denseness.

Two factors have thus been brought out, which through controlling the amount of space to be occupied by cement paste, determine the strength attainable with given amounts of cement. These factors are: Aggregate voidage and the extent to which this voidage is increased by the cement paste pushing the aggregate particles apart.

225. Strength Curves.—The plotting of Strength Curves, as illustrated in Fig. 99 (mixtures ranging from straight gravel, through half gravel and half sand, down to straight sand), is the main step necessary in order to understand the basic principles affecting the choice of aggregates for economical concrete. Assuming certain proportions of cement, in this instance, 1 part

of cement to 4 parts of aggregate, the curves show that coarse sand gives stronger concrete than fine sand, and that the larger

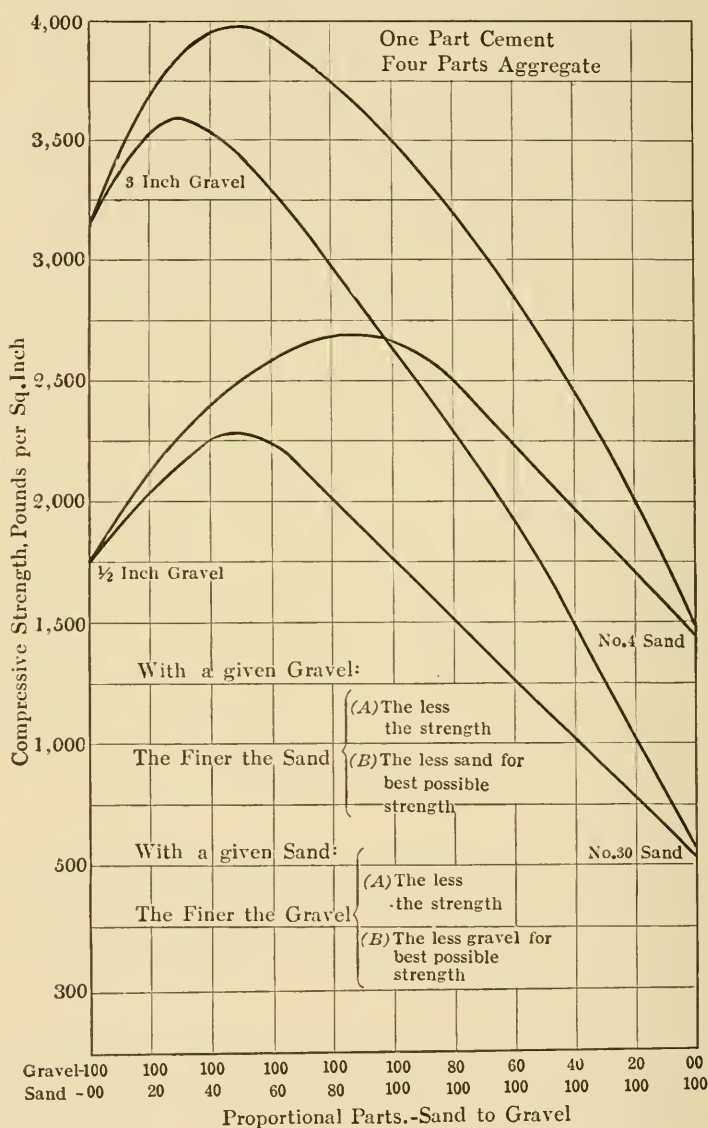


FIG. 99.—Strength curves.

the coarse aggregate the stronger the concrete. Having 4 aggregates, 2 being coarse and 2 sand, each coarse aggregate (in

this illustration, gravel) may be used with each sand, and therefore, there are four curves shown, relative to which the following observations may be made.

(a) The highest curve (maximum strength) represents combinations of coarse gravel and coarse sand.

(b) The lowest curve (minimum strength) represents combinations of fine gravel and fine sand.

(c) The gravel has more influence upon strength than the sand. With either sand, when the coarse gravel is used, a strength above 3,500 lb. may be obtained, while with the fine gravel, even when using the favorable coarse sand, only a strength approximately 1,000 lb. below 3,500 can be reached.

(d) Substituting coarse sand for fine, moves the peak of the strength curve toward larger proportions of sand; and substituting fine gravel for coarse, also moves the peak toward larger proportions of sand. Thus maximum proportions of sand are called for by fine gravel—coarse sand mixtures; and maximum proportions of gravel, by coarse gravel—fine sand mixtures.

Strength curves should be plotted for aggregates peculiar to each locality because dependence cannot be placed upon applying to local aggregates data obtained in investigating foreign aggregates which seem to be similar to the local ones. Difference in grading has a large effect, as for example, a 3-in. gravel devoid of all material less than 2 in. will require a larger ratio of sand than if the gravel were graded down to the No. 4 size. The general outline of strength curves depends upon aggregate voidages, upon the shapes and sizes of the individual voids and upon other qualities of the aggregates. Thus a broken stone having the same sieve analysis as a certain gravel will not necessarily be represented by an identical strength curve. In the following paragraphs the practical application of the strength curve fundamentals are illustrated, using as examples, aggregates from the Potomac River.

226. The Economy of Proper Design.—For many years a 1:3:7 mixture, 6 in. thick, using 1½-in. Potomac River gravel as the coarse aggregate, has been used for concrete base for roadways. In the belief that modern conditions call for a better base, the first thought of many has been that the step to be taken in this direction should be to a 1:3:6 mixture (commonly specified for gravity walls and foundations). For one course roadways, until recently, a 1:2:4 mixture, with 1½-in. gravel was used, then a

change was made to $1:2\frac{1}{4}:3\frac{3}{8}$ (for two reasons; to increase the cement content, and to afford accurate wheelbarrow measurement, since local barrows hold $2\frac{1}{4}$ cu. ft. when struck off level).

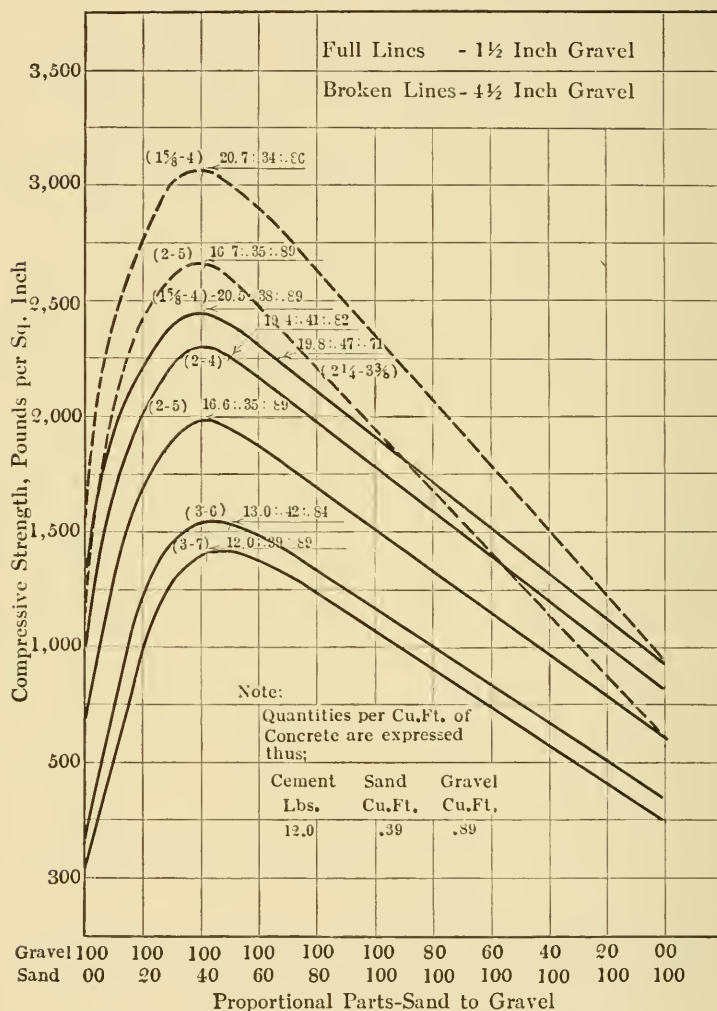


FIG. 100.—Comparison of Potomac River aggregates.

The five strength curves, Fig. 100, drawn in full lines, starting with the lower one, represent combinations of 1 part cement to 10, 9, 7, 6 and $5\frac{5}{8}$ parts of aggregate respectively; the aggregate

being No. 4 sand and $1\frac{1}{2}$ -in. gravel. Plotted on the curves are the mixtures which have been mentioned, and then in addition two curves (broken lines) are shown based on the use of $4\frac{1}{2}$ -in. gravel for combinations of 1 part cement to 7 parts of aggregate and $5\frac{5}{8}$ of aggregate. Data pertaining to the various mixtures are shown in the accompanying Table X. Under the present status of our knowledge of concrete, as used in pavements, it must be assumed that strength is a direct measure of worth. In considering the economy of particular mixtures, strengths, in their relation to costs, have to be compared. In the table the costs for materials are net, and therefore in making up the costs of the complete pavement from 5 to 10 per cent should be added to cover waste, the amount depending upon the conditions under which construction is carried on. The costs of the complete pavement are made up in the same manner as illustrated in "Cost Data," Chap. XIII.

One point to be noted particularly about the $1\frac{1}{2}$ -in. gravel mixtures for one course work is that the $1:2\frac{1}{4}:3\frac{3}{8}$ mixture gives exactly the same strength as a 1:2:4 mixture. If one bag of cement is to be used with $5\frac{5}{8}$ cu. ft. of aggregate the best proportion is $1:1\frac{5}{8}:4$ at the peak of the curve, giving a strength of 2,460 lb. per. square inch, a gain of 9 per cent over a 2:4 mixture and at an increased cost of but 2 per cent. With wheelbarrow charging of a four-bag mixer the $1\frac{5}{8}:4$ proportion is approximated by four bags of cement, 3 barrows of sand and 7 of gravel. Considering the $1\frac{1}{2}$ -in. gravel mixtures, for base construction, a change from 1:3:7 to 1:2:5 gives 40 per cent extra strength at but 11 per cent extra cost and is a more worth while change than to 1:3:6 which gives an 8 per cent gain at an extra cost of 3 per cent. With a gain of 40 per cent in strength by changing from a 1:3:7 to a 1:2:5 mixture it is believed that more benefit is obtained than by increasing the thickness of a 1:3:7 base from 6 to 7 in. The ratio of increased costs is 111 per cent for enriching the mixture to 117 per cent for increasing the thickness. (Whether the concrete base should be made richer, rather than thicker, is a problem requiring much investigation along lines which have thus far been hardly touched by the highway engineer.)

The preceding examples with $1\frac{1}{2}$ -in. gravel show plainly the importance of strength curves if a definite knowledge is to be had of the relative values of different mixtures with any one particular aggregate.

TABLE X.—DATA OF MIXTURES, AS USED IN STRENGTH CURVES

Proportion	Size of gravel, inches	Quantities per cubic foot concrete			Cost per cubic foot of concrete				6-in. pavement, 4½ cu. ft. per square yard	Strength of concrete	Percentage comparison				
		Cement, pounds	Sand, cubic feet	Gravel, cubic feet	Cement at 0.68 cts. per pound	Sand at 3.8 cts. per cubic foot	Gravel at 6 cts. per cubic foot	Total, cents			Material per square yard	Complete per square yard	Pounds per square inch	Cost	Strength
1:3:7	1½	12.0	0.39	0.89	8.1	1.5	5.4	15.0	\$0.67	\$1.53	1,425	100	100		
1:3:6	1½	13.0	0.42	0.84	8.7	1.6	5.0	15.3	0.69	1.57	1,540	103	108		
1:2:5	1½	16.6	0.35	0.89	11.3	1.3	5.4	18.0	0.81	1.70	1,990	111	140		
1:2:5	4½	16.7	0.35	0.89	11.4	1.3	5.4	18.1	0.81	1.70	2,675	111	188		
1:2:4	1½	19.0	0.41	0.82	12.9	1.6	4.9	19.4	0.87	1.88	2,260	100	100		
1:2¼:3¾	1½	19.8	0.47	0.71	13.4	1.8	4.3	19.5	0.88	1.89	2,260	100	100		
1:1½:4	1½	20.5	0.33	0.89	13.9	1.3	5.4	20.6	0.93	1.94	2,460	103	109		
1:1½:4	4½	20.7	0.34	0.86	14.1	1.3	5.2	20.6	0.93	1.94	3,075	103	136		

Their still greater importance is brought out, however, when attention is given to the curves for the $4\frac{1}{2}$ -in. gravel. During many years vast quantities, of what is really the best part of Potomac River gravel, have been wasted overboard as tailings from the dredges while 1 and $1\frac{1}{2}$ -in. products were turned out for roadways and heavy foundations. An exceptionally good sample of $1\frac{1}{2}$ -in. gravel is shown in Fig. 101, and yet, simply by retaining larger pieces, thereby obtaining an aggregate such as the $4\frac{1}{2}$ -in. gravel shown in the illustration, a concrete is obtained with more than 500 lb. greater strength than when this

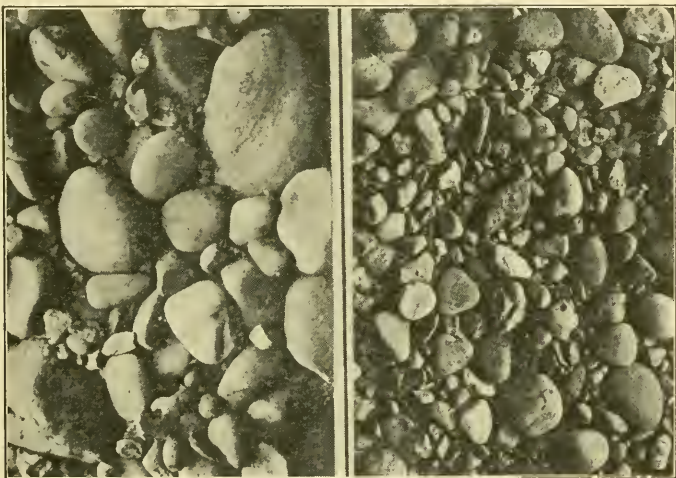


FIG. 101.—Left, $4\frac{1}{2}$ -in. gravel. Right, $1\frac{1}{2}$ -in. gravel.

$1\frac{1}{2}$ -in. sample is used, and the cost not appreciably increased. Four and one-half-inch gravel, as illustrated, has been used successfully in 6-in. one course pavement in the proportion, four bags of cement, three barrows of sand, and seven barrows of gravel (barrows = $2\frac{1}{4}$ cu. ft.). This gives a guaranteed strength of 3,000 lb. per square inch, which is considered just about right for one course work. For base construction 2,000 lb. per square inch is believed to be sufficient, in which case it is not necessary to change the old 1:3:7 proportion since with it and using $4\frac{1}{2}$ -in. gravel instead of $1\frac{1}{2}$ -in., 2,000 lb. per square inch may be obtained.

227. Estimating Chart.—A chart containing a set of strength curves together with such data as are shown in Fig. 102 gives a

complete history of any chosen aggregates (in the illustration Potomac River 0-No. 4 sand and No. 4—1½-in. gravel). In working up this chart, data for each curve should be tabulated somewhat as shown in the accompanying Table XI. For each determination slightly more than 1 cu. ft. of concrete should be

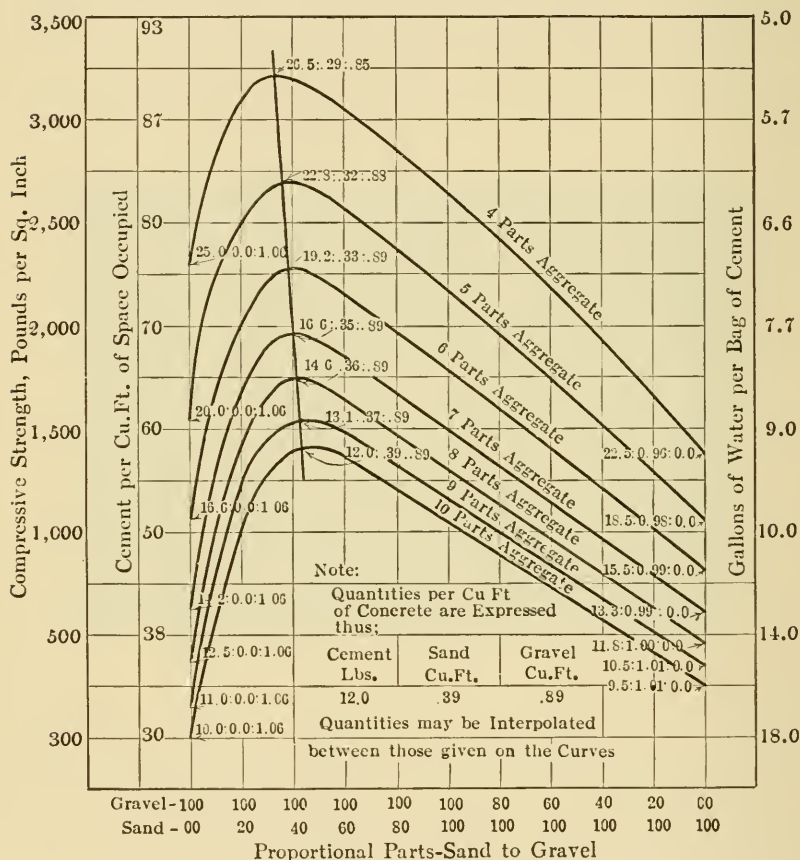


FIG. 102.—Estimating curves.

made. For each of the three critical proportions, $100/20$, $100/40$, and $100/60$, three determinations should be made; and in each case three 6 by 12-in. cylinders made for the compression test. If no testing machine is available, entire dependence will have to be placed on the cement-space and cement-water ratios for strengths.

The peaks of the strength curves do not lie vertically one above the other, but, what might be called the common diameter of the curves, slopes towards larger proportions of gravel as the mixtures are made richer, evidently the larger quantities of cement permitting a reduction in sand. It is interesting to note, while lean mixtures of straight gravel and cement are not as strong as equal amounts of sand and cement, that richer mixtures with gravel surpass those with sand. For instance, a 1:4 mixture using gravel gives 2,325 lb. per square inch, whereas 1:4 with sand gives but 1,400 lb. per square inch. With large size coarse aggregates the strength of concrete is approximately that of its mortar. Thus, to a 1:2 mortar giving a strength of 2,750 lb. per square inch, 5 cu. ft. of $4\frac{1}{2}$ -in. gravel may be added, and the resulting mixture though having a volume several times that of the original mortar will have approximately the same strength, 2,750 lb. per square inch.

In plotting curves it is worth noting that when the consistency of the concrete

TABLE XI.—DATA FOR STRENGTH CURVES—1 CEMENT : 4 AGGREGATE

(Specific gravity of aggregate = 2.63) (Slump, $1\frac{1}{2}$ in.)

A	B	C	D	E	F	G	H	I	J	K	L
Proportion	Sand	Gravel	Weight	Cement	Water	Water per bag of cement	Absolute volume of aggregate	Volume of concrete	Space in concrete	Cement per cubic foot of space	Strength
	Measured Cubic feet	Measured Cubic feet	Weighed Pounds	$94 \times \frac{1.2}{4}$ Pounds	Measured Gallons	$94 \times \frac{F}{E}$ Gallons	$\frac{164.4}{D}$ Cubic feet	Measured Cubic feet	$I-H$ Cubic feet	J Pounds	Test Pounds per square inch
10% ₂₀	0.200	1.000	120	28.2	1.59	5.30	0.73	1.088	0.358	78.3	3,100
10% ₄₀	0.343	0.857	120	28.2	1.66	5.55	0.73	1.080	0.350	80.0	3,225
10% ₆₀	0.450	0.750	120	28.2	1.68	5.60	0.73	1.091	0.361	78.0	3,075

is maintained constant (in the present instance, a consistency suitable for pavements) and the aggregates are not changed, nor the ratio of sand to coarse aggregate; then the addition of each 1 per cent of cement for lean mixtures, increases the strength of the concrete by approximately 1 per cent. Thus, assuming for example, 40 parts of sand to 100 of gravel, a 1 cement : 9 aggregate mixture has $\frac{10}{9}$ the strength of a 1 cement : 10 aggregate mixture, therefore if the latter is 1,400 lb. per square inch the former is about 1,550 lb. per square inch. A 1:7 mixture has $\frac{10}{7}$ the strength of a 1:10, and is therefore about 2,000 lb. per square inch. As the mixtures are made richer and richer the 1 per cent rule fails rapidly, thus, a 1:4 mixture is not quite twice as strong as a 1:8 and a 1:2 mixture has far from 200 per cent of the 1:4 strength, because the limit of strength is that of neat cement which may be no more than 7,000 or 8,000 lb. per square inch.

For lean mixtures a 1 per cent increase in cement gives close to 1 per cent increase in pounds of cement per cubic foot of concrete. As the quantity of cement is increased, a bulking effect takes place. For example, a quarter bag of cement may be mixed with 1 cu. ft. of aggregate and give less than 1 cu. ft. of concrete. If the cement is increased to 400 per cent, that is to one bag, and mixed with 1 cu. ft. of aggregate, much more than 1 cu. ft. of concrete will be obtained, and therefore, the increase to 400 per cent cement does not give an equal increase in pounds of cement per cubic foot of concrete, this latter being not much more than 200 per cent.

228. Proportioning by the Use of Tables.—The accurate way to know one's concrete with its elements such as strength, quantities of material, etc., is through investigation such as has been outlined in preceding paragraphs. Concrete is about 0.7 of the volume of the sum of the aggregate and cement volumes. When the aggregates consist of relatively large particles, the factor is somewhat smaller, and when the aggregates are finer the factor is somewhat larger but for aggregates common to most pavement work a factor of 0.7 gives a good working rule-of-thumb. Thus, for example, one bag of cement, 2 cu. ft. of sand, and 4 cu. ft. of gravel may be assumed to give 0.7×7 or 4.9 cu. ft. of concrete, one bag of cement and 2 cu. ft. of sand, to give 0.7×3 or 2.1 cu. ft. of mortar.

For many years in the past, Taylor and Thompson's tables of quantities have been used for estimating purposes; but they

have one short coming in that they give no idea of the strength that may be expected from the use of given proportions.

Bulletin 9, Structural Materials Research Laboratory, Lewis Institute, Chicago, contains tables for "Proportions and Quantities of Materials for Concrete of a Given Compressive Strength." Portions of these tables are included in the 1921 Joint Committee Report in order to furnish a guide in determining the proportions of materials required to produce a concrete of a given strength. In making use of the tables, which are given herewith, the size to be assigned to a given aggregate is determined on the following basis:

1. At least 15 per cent shall be retained on the sieve next smaller than that considered the maximum size.
2. Not more than 15 per cent of a given coarse aggregate shall be finer than the sieve considered as the minimum size.

SUMMARY OF PRECAUTIONS TO BE OBSERVED IN THE USE OF TABLES

1. If the proportions to be used in the work are selected from the tables, without preliminary tests of the materials, and control tests are not made during the progress of the work, the mixtures in bold-faced type should be used.

2. Strengths were based on 28-day compression tests of 6 by 12-in. concrete cylinders puddled in the forms, cured in a damp place at normal temperatures and tested in a damp condition. Allowance must be made for lower strength resulting from temperatures below normal.

3. Portland cement should meet the requirements of the standard specifications.

4. Aggregate should be clean, structurally sound, and graded in size between the limits shown in the tables.

5. Concrete should be mixed at least 1 min. in a batch mixer of approved design.

6. In comparing the strengths of concrete specimens made on the work with the values in the tables, it is important that tests be made in accordance with standard methods.

7. The quantities of materials were based on measurements in the laboratory using dry materials rodded or puddled into the measure. No allowance was made for waste.

8. The slump test should not be too strictly interpreted.

9. Proportions and quantities of materials may be interpolated for concrete strengths, aggregate sizes and consistencies not covered by the tables.

TABLE XII.—PROPORTIONS FOR 1,500 LB. PER SQUARE INCH CONCRETE

Based on 28-day compressive strength of 6 by 12-in. cylinders.
 Proportions are expressed by volume as follows: Portland cement: Fine Aggregate: Coarse Aggregate.
 Thus 1:2.6:4.6 indicates 1 part by volume of portland cement, 2.6 parts by volume of fine aggregate and 4.6 parts by volume of coarse aggregate.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Proportions using fine aggregate of different sizes				
		0-No. 30	0-No. 16	0-No. 8	0-No. 4	0- $\frac{3}{8}$ in.
None.....	$\frac{1}{2}$ to 1	1:2.8	1:3.2	1:3.8	1:4.4	1:5.1
	3 to 4	1:2.4	1:2.8	1:3.3	1:3.8	1:4.5
	6 to 7	1:1.9	1:2.2	1:2.6	1:3.0	1:3.6
	8 to 10	1:1.4	1:1.6	1:1.8	1:2.1	1:2.5
No. 4 to $\frac{3}{4}$ in....	$\frac{1}{2}$ to 1	1:2.6:4.6	1:2.9:4.3	1:3.4:4.1	1:3.9:3.6	1:4.6:3.1
	3 to 4	1:2.3:4.0	1:2.6:3.8	1:2.9:3.6	1:3.4:3.2	1:4.1:2.8
	6 to 7	1:1.8:3.4	1:2.0:3.2	1:2.3:3.1	1:2.6:2.8	1:3.1:2.6
	8 to 10	1:1.1:2.5	1:1.3:2.4	1:1.5:2.4	1:1.7:2.2	1:2.1:2.0
No. 4 to 1 in....	$\frac{1}{2}$ to 1	1:2.4:5.3	1:2.7:5.2	1:3.1:5.0	1:3.5:4.7	1:4.3:4.3
	3 to 4	1:2.1:4.7	1:2.4:4.5	1:2.7:4.4	1:3.1:4.1	1:3.7:3.7
	6 to 7	1:1.6:3.9	1:1.8:3.8	1:2.1:3.7	1:2.4:3.5	1:2.9:3.3
	8 to 10	1:1.1:2.9	1:1.2:2.8	1:1.4:2.8	1:1.6:2.7	1:1.9:2.5
No. 4 to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:2.4:6.0	1:2.7:5.9	1:3.1:5.8	1:3.5:5.4	1:4.1:5.1
	3 to 4	1:2.0:5.4	1:2.3:5.3	1:2.7:5.2	1:3.0:5.0	1:3.5:4.6
	6 to 7	1:1.6:4.4	1:1.8:4.3	1:2.0:4.3	1:2.3:4.1	1:2.7:3.9
	8 to 10	1:1.0:3.3	1:1.1:3.2	1:1.3:3.2	1:1.5:3.1	1:1.8:2.9
No. 4 to 2 in....	$\frac{1}{2}$ to 1	1:2.2:6.9	1:2.4:6.8	1:2.8:6.8	1:3.1:6.6	1:3.7:6.4
	3 to 4	1:1.8:6.2	1:2.0:6.1	1:2.4:6.1	1:2.7:6.0	1:3.1:5.7
	6 to 7	1:1.4:5.1	1:1.6:5.0	1:1.8:5.0	1:2.0:5.0	1:2.4:4.8
	8 to 10	1:0.9:3.8	1:1.0:3.8	1:1.1:3.8	1:1.3:3.8	1:1.5:3.7
$\frac{3}{8}$ to 1 in.....	$\frac{1}{2}$ to 1	1:2.8:5.2	1:3.1:5.1	1:3.6:4.8	1:4.2:4.6	1:4.8:4.1
	3 to 4	1:2.4:4.5	1:2.6:4.5	1:3.1:4.3	1:3.6:4.0	1:4.1:3.6
	6 to 7	1:1.9:3.9	1:2.1:3.7	1:2.4:3.6	1:2.8:3.4	1:3.2:3.1
	8 to 10	1:1.3:2.8	1:1.4:2.8	1:1.6:2.7	1:1.9:2.6	1:2.2:2.4
$\frac{3}{8}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:2.8:5.8	1:3.1:5.7	1:3.5:5.5	1:4.1:5.3	1:4.7:4.9
	3 to 4	1:2.4:5.2	1:2.7:5.1	1:3.1:5.0	1:3.5:4.8	1:4.1:4.4
	6 to 7	1:1.9:4.3	1:2.1:4.2	1:2.4:4.2	1:2.7:4.0	1:3.1:3.7
	8 to 10	1:1.2:3.2	1:1.4:3.2	1:1.6:3.1	1:1.8:3.0	1:2.1:2.9
$\frac{3}{8}$ to 2 in.....	$\frac{1}{2}$ to 1	1:2.7:6.6	1:3.0:6.6	1:3.4:6.5	1:3.9:6.4	1:4.4:6.0
	3 to 4	1:2.3:5.9	1:2.6:5.9	1:2.9:5.8	1:3.3:5.6	1:3.7:5.5
	6 to 7	1:1.8:4.9	1:2.0:4.8	1:2.2:4.8	1:2.6:4.8	1:3.0:4.5
	8 to 10	1:1.2:3.7	1:1.3:3.7	1:1.5:3.7	1:1.7:3.6	1:1.9:3.5
$\frac{3}{4}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:3.2:5.4	1:3.6:5.3	1:4.1:5.1	1:4.7:4.8	1:5.3:4.4
	3 to 4	1:2.8:4.8	1:3.2:4.8	1:3.6:4.6	1:4.0:4.4	1:4.6:4.0
	6 to 7	1:2.1:4.0	1:2.5:4.0	1:2.8:3.9	1:3.2:3.7	1:3.5:3.4
	8 to 10	1:1.5:3.0	1:1.7:3.0	1:1.9:2.9	1:2.2:2.8	1:2.5:2.7
$\frac{3}{4}$ to 2 in.....	$\frac{1}{2}$ to 1	1:3.2:6.2	1:3.6:6.1	1:4.0:6.0	1:4.6:5.8	1:5.2:5.4
	3 to 4	1:2.8:5.5	1:3.1:5.5	1:3.5:5.4	1:3.9:5.2	1:4.5:4.9
	6 to 7	1:2.1:4.5	1:2.4:4.6	1:2.7:4.5	1:3.1:4.4	1:3.5:4.1
	8 to 10	1:1.4:3.4	1:1.6:3.4	1:1.8:3.4	1:2.1:3.4	1:2.4:3.3
$\frac{3}{4}$ to 3 in.....	$\frac{1}{2}$ to 1	1:3.2:7.1	1:3.6:7.1	1:4.0:7.0	1:4.6:6.9	1:5.2:6.6
	3 to 4	1:2.7:6.3	1:3.0:6.3	1:3.4:6.3	1:4.0:6.2	1:4.5:5.9
	6 to 7	1:2.1:5.1	1:2.4:5.2	1:2.7:5.2	1:3.1:5.1	1:3.5:4.9
	8 to 10	1:1.4:3.8	1:1.6:3.9	1:1.8:3.9	1:2.1:3.9	1:2.4:3.8

TABLE XIII.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF 1,500 LB. PER SQUARE INCH CONCRETE

The volume of cement is expressed in barrels and of aggregates in cubic yards.

F = fine aggregate; C = coarse aggregate.

Quantities are net, no allowance being made for waste; for average conditions, the following additions are suggested: Cement, 2 per cent; fine aggregate, 10 per cent; coarse aggregate, 5 per cent.

See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Quantities of materials using fine aggregate of different sizes														
		0-No. 30			0-No. 16			0-No. 8			0-No. 4			0-3s in.		
		Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement
		F	C		F	C		F	C		F	C		F	C	
None	$\frac{1}{2}$ to 1	1.90	0.79	.....	1.77	0.84	.....	1.60	0.90	.....	1.36	0.89	.....	1.27	0.96	.....
	3 to 4	2.12	0.75	.....	1.96	0.81	.....	1.75	0.86	.....	1.52	0.86	.....	1.38	0.92	.....
	6 to 7	2.49	0.70	.....	2.33	0.76	.....	2.08	0.80	.....	1.81	0.80	.....	1.64	0.88	.....
	8 to 10	2.98	0.62	.....	2.82	0.67	.....	2.36	0.70	.....	2.32	0.72	.....	2.10	0.78	.....
No. 4 to $\frac{3}{4}$ in.	$\frac{1}{2}$ to 1	1.02	0.39	0.69	1.02	0.44	0.66	1.01	0.51	0.61	0.98	0.56	0.52	0.98	0.67	0.45
	3 to 4	1.17	0.40	0.69	1.12	0.43	0.63	1.11	0.48	0.59	1.07	0.54	0.51	1.08	0.65	0.45
	6 to 7	1.39	0.37	0.70	1.36	0.40	0.64	1.31	0.45	0.60	1.30	0.50	0.54	1.27	0.58	0.47
	8 to 10	1.76	0.29	0.65	1.76	0.34	0.63	1.73	0.38	0.61	1.68	0.42	0.55	1.67	0.52	0.49
No. 4 to 1 in.	$\frac{1}{2}$ to 1	0.98	0.35	0.77	0.98	0.39	0.75	0.96	0.44	0.71	0.94	0.49	0.65	0.93	0.59	0.59
	3 to 4	1.08	0.34	0.75	1.06	0.38	0.70	1.05	0.42	0.68	1.02	0.47	0.62	1.02	0.56	0.56
	6 to 7	1.32	0.31	0.76	1.30	0.35	0.73	1.23	0.38	0.67	1.21	0.43	0.63	1.21	0.52	0.59
	8 to 10	1.70	0.28	0.73	1.68	0.30	0.70	1.64	0.34	0.68	1.60	0.38	0.64	1.57	0.44	0.58
No. 4 to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	0.93	0.33	0.83	0.93	0.37	0.81	0.91	0.42	0.78	0.88	0.46	0.70	0.86	0.52	0.65
	3 to 4	1.02	0.30	0.81	1.03	0.35	0.81	1.01	0.40	0.78	0.98	0.43	0.72	0.97	0.50	0.66
	6 to 7	1.24	0.29	0.81	1.23	0.33	0.78	1.18	0.35	0.75	1.12	0.38	0.68	1.15	0.46	0.66
	8 to 10	1.62	0.24	0.79	1.59	0.26	0.75	1.54	0.30	0.73	1.50	0.33	0.69	1.50	0.40	0.64
No. 4 to 2 in.	$\frac{1}{2}$ to 1	0.88	0.29	0.90	0.88	0.31	0.88	0.85	0.35	0.86	0.82	0.38	0.80	0.80	0.44	0.76
	3 to 4	0.98	0.26	0.90	0.99	0.29	0.89	0.96	0.34	0.87	0.93	0.37	0.82	0.91	0.42	0.77
	6 to 7	1.17	0.27	0.88	1.16	0.28	0.86	1.13	0.30	0.84	1.09	0.32	0.81	1.09	0.39	0.78
	8 to 10	1.53	0.20	0.86	1.49	0.22	0.84	1.46	0.24	0.82	1.43	0.27	0.80	1.43	0.32	0.78
$\frac{3}{8}$ to 1 in.	$\frac{1}{2}$ to 1	1.00	0.41	0.77	0.97	0.44	0.73	0.95	0.51	0.68	0.91	0.56	0.62	0.92	0.65	0.56
	3 to 4	1.08	0.38	0.72	1.05	0.40	0.70	1.03	0.47	0.65	1.00	0.53	0.59	1.02	0.62	0.54
	6 to 7	1.32	0.37	0.76	1.27	0.40	0.70	1.25	0.44	0.67	1.20	0.50	0.60	1.21	0.57	0.56
	8 to 10	1.73	0.33	0.72	1.69	0.35	0.70	1.66	0.39	0.66	1.59	0.45	0.61	1.54	0.50	0.55
$\frac{3}{8}$ to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	0.93	0.38	0.80	0.91	0.42	0.77	0.90	0.47	0.73	0.85	0.52	0.67	0.85	0.59	0.62
	3 to 4	1.03	0.37	0.79	1.01	0.40	0.76	1.00	0.46	0.74	0.95	0.49	0.68	0.96	0.58	0.62
	6 to 7	1.22	0.34	0.78	1.21	0.38	0.75	1.18	0.42	0.73	1.17	0.47	0.69	1.13	0.52	0.62
	8 to 10	1.62	0.29	0.77	1.60	0.33	0.76	1.54	0.36	0.71	1.48	0.39	0.66	1.46	0.45	0.63
$\frac{3}{8}$ to 2 in.	$\frac{1}{2}$ to 1	0.88	0.35	0.86	0.86	0.38	0.84	0.83	0.42	0.80	0.79	0.45	0.75	0.77	0.50	0.68
	3 to 4	0.98	0.33	0.85	0.97	0.37	0.85	0.95	0.41	0.81	0.91	0.44	0.75	0.90	0.49	0.73
	6 to 7	1.16	0.31	0.84	1.14	0.34	0.81	1.11	0.36	0.79	1.08	0.42	0.77	1.07	0.48	0.71
	8 to 10	1.51	0.28	0.87	1.50	0.29	0.82	1.45	0.32	0.79	1.40	0.35	0.75	1.38	0.39	0.71
$\frac{3}{4}$ to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	0.91	0.43	0.73	0.89	0.47	0.70	0.87	0.53	0.66	0.82	0.57	0.58	0.81	0.63	0.53
	3 to 4	1.00	0.41	0.71	1.00	0.47	0.71	0.97	0.52	0.66	0.93	0.55	0.60	0.91	0.62	0.54
	6 to 7	1.20	0.37	0.71	1.20	0.44	0.71	1.15	0.48	0.66	1.11	0.53	0.61	1.08	0.56	0.54
	8 to 10	1.60	0.36	0.71	1.57	0.39	0.70	1.52	0.43	0.65	1.44	0.47	0.60	1.43	0.53	0.57
$\frac{3}{4}$ to 2 in.	$\frac{1}{2}$ to 1	0.85	0.40	0.78	0.85	0.45	0.77	0.80	0.47	0.71	0.76	0.52	0.65	0.74	0.57	0.59
	3 to 4	0.96	0.40	0.78	0.95	0.44	0.77	0.92	0.48	0.73	0.84	0.48	0.65	0.86	0.57	0.62
	6 to 7	1.14	0.35	0.76	1.14	0.41	0.78	1.08	0.43	0.72	1.03	0.47	0.67	1.04	0.54	0.63
	8 to 10	1.50	0.31	0.75	1.46	0.35	0.73	1.43	0.38	0.72	1.37	0.43	0.69	1.34	0.48	0.65
$\frac{3}{4}$ to 3 in.	$\frac{1}{2}$ to 1	0.78	0.37	0.82	0.76	0.40	0.80	0.72	0.43	0.75	0.67	0.46	0.68	0.65	0.50	0.63
	3 to 4	0.91	0.36	0.85	0.89	0.40	0.83	0.86	0.43	0.80	0.81	0.48	0.74	0.79	0.53	0.69
	6 to 7	1.04	0.32	0.79	1.04	0.37	0.80	1.03	0.41	0.79	0.98	0.45	0.88	0.99	0.51	0.72
	8 to 10	1.43	0.30	0.80	1.39	0.33	0.80	1.35	0.36	0.78	1.30	0.40	0.75	1.25	0.44	0.70

TABLE XIV.—PROPORTIONS FOR 2,000 LB. PER SQUARE INCH CONCRETE

Based on 28-day compressive strength of 6 by 12-in. cylinders.
 Proportions are expressed by volume as follows: Portland Cement: Fine Aggregate:
 Coarse Aggregate.
 Thus 1:2.6:4.6 indicates 1 part by volume of portland cement, 2.6 parts by volume of
 fine aggregate and 4.6 parts by volume of coarse aggregate.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Proportions using fine aggregate of different sizes				
		0-No. 30	0-No. 16	0-No. 8	0-No. 4	0- $\frac{3}{8}$ in.
None.....	$\frac{1}{2}$ to 1	1:2.2	1:2.6	1:3.0	1:3.5	1:4.1
	3 to 4	1:1.9	1:2.2	1:2.6	1:3.0	1:3.5
	6 to 7	1:1.5	1:1.7	1:2.0	1:2.3	1:2.7
	8 to 10	1:1.0	1:1.1	1:1.3	1:1.6	1:1.8
No. 4 to $\frac{3}{4}$ in...	$\frac{1}{2}$ to 1	1:2.1:3.8	1:2.3:3.7	1:2.6:3.5	1:3.0:3.1	1:3.6:2.8
	3 to 4	1:1.7:3.3	1:1.9:3.2	1:2.2:3.1	1:2.6:2.8	1:3.0:2.4
	6 to 7	1:1.3:2.7	1:1.4:2.6	1:1.7:2.5	1:1.9:2.3	1:2.3:2.1
	8 to 10	1:0.8:1.9	1:0.9:1.9	1:1.0:1.8	1:1.2:1.7	1:1.5:1.6
No. 4 to 1 in....	$\frac{1}{2}$ to 1	1:1.9:4.5	1:2.2:4.3	1:2.5:4.2	1:2.8:3.9	1:3.4:3.6
	3 to 4	1:1.6:3.9	1:1.8:3.8	1:2.1:3.7	1:2.4:3.5	1:2.8:3.2
	6 to 7	1:1.2:3.1	1:1.3:3.1	1:1.5:3.0	1:1.8:2.9	1:2.1:2.7
	8 to 10	1:0.7:2.2	1:0.3:2.2	1:1.0:2.3	1:1.1:2.1	1:1.3:2.0
No. 4 to 1 $\frac{1}{2}$ in..	$\frac{1}{2}$ to 1	1:1.9:5.0	1:2.1:4.9	1:2.4:4.9	1:2.7:4.6	1:3.2:4.4
	3 to 4	1:1.6:4.4	1:1.7:4.3	1:2.0:4.2	1:2.4:4.0	1:2.7:3.8
	6 to 7	1:1.1:3.5	1:1.3:3.5	1:1.4:3.5	1:1.7:3.4	1:2.0:3.2
	8 to 10	1:0.7:2.5	1:0.8:2.5	1:0.9:2.5	1:1.0:2.4	1:1.2:2.3
No. 4 to 2 in....	$\frac{1}{2}$ to 1	1:1.7:5.8	1:1.9:5.7	1:2.1:5.8	1:2.4:5.6	1:2.8:5.5
	3 to 4	1:1.4:5.0	1:1.5:5.0	1:1.8:5.0	1:2.0:4.9	1:2.3:4.7
	6 to 7	1:1.0:4.1	1:1.1:4.1	1:1.2:4.1	1:1.4:4.1	1:1.7:3.9
	8 to 10	1:0.6:2.9	1:0.7:2.9	1:0.7:3.0	1:0.8:2.9	1:1.0:2.9
$\frac{3}{8}$ to 1 in.....	$\frac{1}{2}$ to 1	1:2.2:4.4	1:2.5:4.2	1:2.8:4.1	1:3.3:3.8	1:3.8:3.4
	3 to 4	1:1.9:3.8	1:2.1:3.7	1:2.4:3.6	1:2.8:3.4	1:3.2:3.1
	6 to 7	1:1.4:3.1	1:1.5:3.0	1:1.8:3.0	1:2.1:2.8	1:2.4:2.5
	8 to 10	1:0.9:2.2	1:1.0:2.2	1:1.1:2.2	1:1.3:2.0	1:1.5:1.9
$\frac{3}{8}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:2.2:4.9	1:2.5:4.8	1:2.8:4.7	1:3.2:4.6	1:3.7:4.2
	3 to 4	1:1.9:4.3	1:2.1:4.2	1:2.4:4.1	1:2.7:4.0	1:3.1:3.7
	6 to 7	1:1.4:3.5	1:1.5:3.4	1:1.7:3.4	1:2.0:3.3	1:2.3:3.1
	8 to 10	1:0.9:2.5	1:1.0:2.5	1:1.1:2.4	1:1.3:2.4	1:1.5:2.3
$\frac{3}{8}$ to 2 in.....	$\frac{1}{2}$ to 1	1:2.1:5.6	1:2.3:5.5	1:2.6:5.5	1:3.0:5.4	1:3.5:5.1
	3 to 4	1:1.7:4.8	1:2.0:4.8	1:2.2:4.8	1:2.5:4.7	1:2.9:4.4
	6 to 7	1:1.3:4.0	1:1.4:3.9	1:1.6:3.9	1:1.8:3.9	1:2.1:3.8
	8 to 10	1:0.8:2.9	1:0.9:2.9	1:1.0:2.9	1:1.2:2.9	1:1.3:2.8
$\frac{3}{4}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:2.6:4.5	1:2.9:4.5	1:3.3:4.4	1:3.8:4.2	1:4.3:3.9
	3 to 4	1:2.2:3.9	1:2.5:3.9	1:2.8:3.8	1:3.2:3.6	1:3.6:3.3
	6 to 7	1:1.6:3.2	1:1.8:3.2	1:2.1:3.1	1:2.4:3.0	1:2.7:2.8
	8 to 10	1:1.0:2.3	1:1.2:2.3	1:1.4:2.2	1:1.6:2.2	1:1.8:2.1
$\frac{3}{4}$ to 2 in	$\frac{1}{2}$ to 1	1:2.5:5.2	1:2.8:5.2	1:3.2:5.1	1:3.6:5.0	1:4.1:4.7
	3 to 4	1:2.1:4.5	1:2.4:4.5	1:2.7:4.4	1:3.1:4.3	1:3.5:4.0
	6 to 7	1:1.6:3.7	1:1.8:3.7	1:2.0:3.7	1:2.3:3.6	1:2.6:3.5
	8 to 10	1:1.0:2.6	1:1.1:2.7	1:1.3:2.6	1:1.5:2.7	1:1.7:2.6
$\frac{3}{4}$ to 3 in... ..	$\frac{1}{2}$ to 1	1:2.5:6.0	1:2.9:5.9	1:3.2:5.9	1:3.6:5.8	1:4.1:5.6
	3 to 4	1:2.1:5.1	1:2.4:5.2	1:2.7:5.2	1:3.1:5.1	1:3.5:4.9
	6 to 7	1:1.5:4.1	1:1.7:4.2	1:2.0:4.2	1:2.3:4.2	1:2.6:4.0
	8 to 10	1:1.0:2.9	1:1.1:3.0	1:1.3:3.0	1:1.5:3.0	1:1.7:3.0

TABLE XV.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF 2,000 LB. PER SQUARE INCH CONCRETE

The volume of cement is expressed in barrels and of aggregates in cubic yards.

F = fine aggregate; C = coarse aggregate.

Quantities are net, no allowance being made for waste; for average conditions, the following additions are suggested: Cement, 2 per cent; fine aggregate, 10 per cent; coarse aggregate, 5 per cent.

See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Quantities of materials using fine aggregate of different sizes											
		0-No. 30			0-No. 16			0-No. 8			0-No. 4		
		Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement
		F	C		F	C		F	C		F	C	
None.....	½ to 1	2.31	0.75	....	2.12	0.82	....	1.92	0.85	....	1.65	0.85	....
	3 to 4	2.55	0.72	....	2.39	0.78	....	2.12	0.82	....	1.85	0.82	....
	6 to 7	2.94	0.65	....	2.83	0.71	....	2.52	0.75	....	2.24	0.76	....
	8 to 10	3.60	0.53	....	3.54	0.58	....	3.25	0.62	....	2.80	0.66	....
No. 4 to ¾ in..	½ to 1	1.27	0.40	0.71	1.24	0.42	0.68	1.19	0.46	0.62	1.17	0.52	0.54
	3 to 4	1.43	0.36	0.70	1.40	0.39	0.66	1.36	0.44	0.62	1.34	0.51	0.56
	6 to 7	1.71	0.33	0.68	1.70	0.35	0.66	1.66	0.42	0.61	1.60	0.45	0.54
	8 to 10	2.25	0.27	0.63	2.23	0.30	0.63	2.20	0.33	0.59	2.13	0.38	0.54
No. 4 to 1 in...	½ to 1	1.19	0.33	0.79	1.17	0.38	0.74	1.13	0.42	0.70	1.10	0.46	0.64
	3 to 4	1.36	0.32	0.78	1.32	0.35	0.74	1.26	0.39	0.69	1.24	0.44	0.64
	6 to 7	1.55	0.29	0.76	1.62	0.31	0.74	1.56	0.35	0.69	1.52	0.40	0.65
	8 to 10	2.15	0.22	0.70	2.13	0.25	0.69	2.07	0.31	0.70	2.01	0.33	0.63
No. 4 to 1½ in.	½ to 1	1.10	0.31	0.81	1.09	0.34	0.79	1.07	0.38	0.78	1.05	0.42	0.71
	3 to 4	1.26	0.30	0.82	1.25	0.31	0.79	1.20	0.35	0.74	1.17	0.42	0.69
	6 to 7	1.54	0.25	0.80	1.52	0.29	0.79	1.47	0.30	0.76	1.44	0.36	0.72
	8 to 10	2.04	0.21	0.75	2.00	0.24	0.74	1.94	0.26	0.72	1.88	0.28	0.67
No. 4 to 2 in...	½ to 1	1.04	0.26	0.89	1.05	0.29	0.88	1.04	0.32	0.89	1.00	0.35	0.83
	3 to 4	1.20	0.25	0.89	1.19	0.26	0.88	1.16	0.31	0.86	1.11	0.33	0.80
	6 to 7	1.47	0.22	0.89	1.45	0.24	0.88	1.38	0.25	0.84	1.35	0.28	0.82
	8 to 10	1.92	0.17	0.82	1.89	0.20	0.81	1.85	0.19	0.82	1.81	0.21	0.78
¾ to 1 in.....	½ to 1	1.17	0.38	0.76	1.16	0.43	0.72	1.12	0.46	0.68	1.10	0.54	0.62
	3 to 4	1.34	0.38	0.75	1.33	0.41	0.73	1.29	0.46	0.69	1.23	0.51	0.62
	6 to 7	1.67	0.35	0.77	1.63	0.36	0.72	1.57	0.42	0.70	1.51	0.47	0.63
	8 to 10	2.16	0.29	0.70	2.12	0.31	0.69	2.06	0.34	0.67	2.01	0.39	0.60
¾ to 1½ in....	½ to 1	1.10	0.36	0.80	1.07	0.40	0.76	1.05	0.43	0.73	1.02	0.48	0.69
	3 to 4	1.25	0.35	0.79	1.24	0.39	0.77	1.21	0.43	0.73	1.16	0.46	0.69
	6 to 7	1.54	0.32	0.80	1.52	0.34	0.77	1.47	0.37	0.74	1.42	0.42	0.69
	8 to 10	2.05	0.27	0.76	2.00	0.29	0.74	1.93	0.31	0.70	1.89	0.36	0.67
¾ to 2 in.....	½ to 1	1.05	0.33	0.85	1.03	0.35	0.84	1.01	0.39	0.82	0.98	0.43	0.78
	3 to 4	1.19	0.30	0.85	1.18	0.35	0.84	1.14	0.37	0.81	1.10	0.41	0.76
	6 to 7	1.46	0.28	0.86	1.45	0.30	0.84	1.40	0.33	0.81	1.33	0.35	0.77
	8 to 10	1.91	0.23	0.82	1.88	0.25	0.81	1.83	0.27	0.79	1.80	0.32	0.77
¾ to 1½ in....	½ to 1	1.07	0.41	0.71	1.06	0.45	0.71	1.02	0.50	0.66	0.98	0.55	0.61
	3 to 4	1.23	0.40	0.71	1.23	0.45	0.71	1.19	0.49	0.67	1.12	0.53	0.60
	6 to 7	1.51	0.36	0.72	1.49	0.40	0.71	1.45	0.45	0.67	1.36	0.48	0.60
	8 to 10	2.01	0.30	0.69	1.97	0.35	0.67	1.91	0.40	0.62	1.81	0.43	0.59
¾ to 2 in.....	½ to 1	1.02	0.38	0.79	1.02	0.42	0.78	0.99	0.47	0.75	0.94	0.50	0.70
	3 to 4	1.17	0.36	0.78	1.16	0.41	0.77	1.11	0.44	0.72	1.05	0.48	0.67
	6 to 7	1.44	0.34	0.79	1.41	0.38	0.77	1.37	0.41	0.75	1.31	0.45	0.70
	8 to 10	1.88	0.28	0.72	1.85	0.30	0.74	1.82	0.35	0.70	1.74	0.39	0.69
¾ to 3 in.....	½ to 1	0.96	0.36	0.85	0.95	0.41	0.83	0.92	0.44	0.80	0.88	0.47	0.75
	3 to 4	1.08	0.34	0.81	1.08	0.38	0.83	1.05	0.42	0.81	1.00	0.46	0.76
	6 to 7	1.36	0.30	0.83	1.30	0.33	0.81	1.28	0.38	0.80	1.23	0.42	0.77
	8 to 10	1.81	0.27	0.78	1.76	0.29	0.78	1.72	0.33	0.76	1.65	0.37	0.73

TABLE XVI.—PROPORTIONS FOR 2,500 LB. PER SQUARE INCH CONCRETE

Based on 28-day compressive strength of 6 by 12-in. cylinders.
 Proportions are expressed by volume as follows: Portland Cement: Fine Aggregate:
 Coarse Aggregate.
 Thus 1:2.6:4.6 indicates 1 part by volume of portland cement, 2.6 parts by volume of
 fine aggregate and 4.6 parts by volume of coarse aggregate.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Proportions using fine aggregate of different sizes				
		0-No. 30	0-No. 16	0-No. 8	0-No. 4	0- $\frac{3}{8}$ in.
None.....	$\frac{1}{2}$ to 1	1:1.8	1:2.1	1:2.4	1:2.9	1:3.3
	3 to 4	1:1.5	1:1.8	1:2.1	1:2.4	1:2.8
	6 to 7	1:1.1	1:1.3	1:1.6	1:1.8	1:2.1
	8 to 10	1:0.7	1:0.8	1:0.9	1:1.1	1:1.3
No. 4 to $\frac{3}{4}$ in...	$\frac{1}{2}$ to 1	1:1.6:3.2	1:1.8:3.1	1:2.1:3.0	1:2.4:2.7	1:2.9:2.4
	3 to 4	1:1.3:2.8	1:1.5:2.7	1:1.7:2.6	1:2.0:2.4	1:2.4:2.2
	6 to 7	1:1.0:2.2	1:1.1:2.2	1:1.3:2.1	1:1.5:2.0	1:1.8:1.8
	8 to 10	1:0.5:1.4	1:0.6:1.4	1:0.7:1.4	1:0.8:1.4	1:1.0:1.3
No. 4 to 1 in....	$\frac{1}{2}$ to 1	1:1.5:3.7	1:1.7:3.7	1:2.0:3.5	1:2.2:3.4	1:2.7:3.1
	3 to 4	1:1.2:3.3	1:1.4:3.2	1:1.6:3.1	1:1.9:3.0	1:2.2:2.7
	6 to 7	1:0.9:2.6	1:1.0:2.6	1:1.1:2.5	1:1.3:2.4	1:1.6:2.3
	8 to 10	1:0.5:1.7	1:0.6:1.7	1:0.6:1.7	1:0.7:1.6	1:0.9:1.5
No. 4 to 1 $\frac{1}{2}$ in..	$\frac{1}{2}$ to 1	1:1.4:4.2	1:1.6:4.1	1:1.9:4.1	1:2.2:4.0	1:2.5:3.8
	3 to 4	1:1.2:3.7	1:1.3:3.6	1:1.5:3.6	1:1.8:3.5	1:2.1:3.3
	6 to 7	1:0.9:2.9	1:0.9:2.8	1:1.1:2.8	1:1.3:2.8	1:1.6:2.6
	8 to 10	1:0.5:1.9	1:0.5:1.9	1:0.6:1.9	1:0.7:1.8	1:0.8:1.8
No. 4 to 2 in....	$\frac{1}{2}$ to 1	1:1.3:4.9	1:1.4:4.8	1:1.6:4.9	1:1.9:4.8	1:2.2:4.7
	3 to 4	1:1.1:4.3	1:1.2:4.2	1:1.3:4.3	1:1.6:4.2	1:1.8:4.1
	6 to 7	1:0.7:3.3	1:0.8:3.3	1:0.9:3.4	1:1.1:3.3	1:1.2:3.3
	8 to 10	1:0.4:2.2	1:0.4:2.2	1:0.5:2.2	1:0.6:2.2	1:0.6:2.2
$\frac{3}{8}$ to 1 in.....	$\frac{1}{2}$ to 1	1:1.8:3.7	1:2.0:3.6	1:2.3:3.5	1:2.6:3.3	1:3.0:2.9
	3 to 4	1:1.4:3.2	1:1.6:3.1	1:1.9:2.9	1:2.2:2.9	1:2.5:2.6
	6 to 7	1:1.0:2.5	1:1.2:2.5	1:1.3:2.4	1:1.6:2.3	1:1.8:2.2
	8 to 10	1:0.6:1.6	1:0.7:1.6	1:0.8:1.6	1:0.9:1.6	1:1.0:1.5
$\frac{3}{8}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:1.7:4.1	1:1.9:4.1	1:2.2:4.0	1:2.5:3.9	1:2.9:3.6
	3 to 4	1:1.5:3.6	1:1.6:3.6	1:1.8:3.5	1:2.1:3.4	1:2.3:3.2
	6 to 7	1:1.0:2.9	1:1.2:2.8	1:1.3:2.8	1:1.6:2.7	1:1.8:2.6
	8 to 10	1:0.6:1.9	1:0.6:1.9	1:0.8:1.8	1:0.9:1.8	1:1.0:1.8
$\frac{3}{8}$ to 2 in.....	$\frac{1}{2}$ to 1	1:1.7:4.7	1:1.8:4.7	1:2.1:4.7	1:2.4:4.6	1:2.7:4.4
	3 to 4	1:1.4:4.1	1:1.5:4.1	1:1.7:4.1	1:2.0:4.0	1:2.3:3.9
	6 to 7	1:1.0:3.2	1:1.1:3.2	1:1.2:3.2	1:1.4:3.2	1:1.6:3.1
	8 to 10	1:0.5:2.1	1:0.6:2.1	1:0.7:2.2	1:0.8:2.2	1:0.9:2.1
$\frac{3}{4}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:2.0:3.8	1:2.3:3.8	1:2.6:3.7	1:3.0:3.6	1:3.4:3.3
	3 to 4	1:1.7:3.3	1:2.0:3.3	1:2.2:3.2	1:2.5:3.2	1:2.9:2.9
	6 to 7	1:1.2:2.6	1:1.4:2.6	1:1.6:2.6	1:1.9:2.5	1:2.1:2.3
	8 to 10	1:0.7:1.7	1:0.8:1.7	1:0.9:1.7	1:1.1:1.7	1:1.2:1.6
$\frac{3}{4}$ to 2 in.....	$\frac{1}{2}$ to 1	1:2.0:4.4	1:2.2:4.4	1:2.5:4.3	1:2.9:4.3	1:3.3:4.1
	3 to 4	1:1.7:3.8	1:1.9:3.8	1:2.1:3.8	1:2.5:3.7	1:2.8:3.6
	6 to 7	1:1.2:3.0	1:1.4:3.0	1:1.6:3.0	1:1.8:3.0	1:2.0:2.8
	8 to 10	1:0.7:2.0	1:0.8:2.0	1:0.9:2.0	1:1.0:2.0	1:1.2:2.0
$\frac{3}{4}$ to 3 in.....	$\frac{1}{2}$ to 1	1:2.0:5.0	1:2.2:5.0	1:2.5:5.0	1:2.7:5.0	1:3.2:4.7
	3 to 4	1:1.7:4.3	1:1.9:4.3	1:2.1:4.3	1:2.4:4.3	1:2.7:4.1
	6 to 7	1:1.2:3.3	1:1.4:3.4	1:1.6:3.4	1:1.8:3.4	1:2.0:3.3
	8 to 10	1:0.7:2.2	1:0.8:2.2	1:0.9:2.2	1:1.0:2.3	1:1.2:2.3

TABLE XVII.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF 2,500 LB. PER SQUARE INCH CONCRETE

The volume of cement is expressed in barrels and of aggregates in cubic yards.

F = fine aggregate; C = coarse aggregate.

Quantities are net, no allowance being made for waste; for average conditions, the following additions are suggested: Cement, 2 per cent; fine aggregate, 10 per cent; coarse aggregate, 5 per cent.

See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Quantities of materials using fine aggregate of different sizes														
		0-No. 30			0-No. 16			0-No. 8			0-No. 4			0-¾ in.		
		Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement
		F	C		F	C		F	C		F	C		F	C	
None.....	½ to 1	2.71	0.72	....	2.53	0.79	....	2.30	0.82	....	1.94	0.83	....	1.83	0.89	....
	3 to 4	3.01	0.67	....	2.78	0.74	....	2.50	0.78	....	2.20	0.78	....	2.05	0.85	....
	6 to 7	3.60	0.59	....	3.38	0.65	....	2.97	0.70	....	2.71	0.72	....	2.45	0.76	....
	8 to 10	4.24	0.44	....	4.11	0.49	....	3.91	0.52	....	3.46	0.56	....	3.16	0.61	....
No. 4 to ¾ in.	½ to 1	1.49	0.35	0.70	1.46	0.39	0.67	1.42	0.44	0.63	1.39	0.49	0.55	1.39	0.60	0.49
	3 to 4	1.68	0.32	0.70	1.67	0.37	0.67	1.63	0.41	0.63	1.57	0.46	0.56	1.54	0.55	0.50
	6 to 7	2.06	0.30	0.67	2.03	0.33	0.66	1.98	0.38	0.62	1.89	0.42	0.56	1.89	0.50	0.50
	8 to 10	2.83	0.21	0.59	2.78	0.25	0.58	2.71	0.28	0.56	2.64	0.31	0.55	2.58	0.38	0.50
No. 4 to 1 in.	½ to 1	1.42	0.32	0.78	1.39	0.35	0.76	1.35	0.40	0.70	1.30	0.42	0.65	1.29	0.51	0.59
	3 to 4	1.61	0.29	0.79	1.56	0.32	0.74	1.51	0.36	0.69	1.48	0.41	0.65	1.47	0.48	0.59
	6 to 7	1.95	0.26	0.75	1.90	0.28	0.70	1.87	0.30	0.69	1.82	0.35	0.65	1.81	0.43	0.62
	8 to 10	2.68	0.19	0.65	2.64	0.23	0.66	2.54	0.23	0.64	2.50	0.26	0.59	2.58	0.33	0.55
No. 4 to 1½ in.	½ to 1	1.31	0.27	0.83	1.32	0.31	0.80	1.25	0.35	0.76	1.23	0.40	0.73	1.23	0.45	0.69
	3 to 4	1.50	0.27	0.82	1.48	0.28	0.79	1.43	0.32	0.76	1.39	0.37	0.72	1.39	0.43	0.68
	6 to 7	1.83	0.24	0.79	1.83	0.24	0.76	1.78	0.29	0.74	1.73	0.33	0.72	1.72	0.38	0.66
	8 to 10	2.50	0.19	0.70	2.49	0.18	0.70	2.42	0.21	0.68	2.40	0.25	0.64	2.39	0.28	0.64
No. 4 to 2 in.	½ to 1	1.25	0.24	0.91	1.24	0.26	0.88	1.21	0.29	0.88	1.17	0.33	0.83	1.13	0.37	0.79
	3 to 4	1.44	0.23	0.92	1.41	0.25	0.88	1.36	0.26	0.87	1.31	0.31	0.81	1.32	0.35	0.80
	6 to 7	1.77	0.18	0.87	1.75	0.21	0.86	1.70	0.23	0.86	1.65	0.27	0.81	1.63	0.29	0.80
	8 to 10	2.43	0.14	0.79	2.42	0.14	0.79	2.38	0.18	0.78	2.32	0.21	0.75	2.31	0.20	0.75
¾ to 1 in.	½ to 1	1.41	0.38	0.77	1.39	0.41	0.74	1.34	0.46	0.69	1.29	0.50	0.63	1.29	0.57	0.55
	3 to 4	1.61	0.33	0.76	1.57	0.37	0.72	1.51	0.42	0.65	1.47	0.48	0.63	1.45	0.54	0.56
	6 to 7	1.97	0.29	0.73	1.91	0.34	0.71	1.87	0.36	0.66	1.83	0.43	0.62	1.78	0.47	0.58
	8 to 10	2.64	0.23	0.62	2.62	0.27	0.62	2.56	0.30	0.61	2.47	0.33	0.58	2.42	0.36	0.54
¾ to 1½ in.	½ to 1	1.32	0.33	0.80	1.30	0.37	0.79	1.27	0.41	0.75	1.22	0.45	0.70	1.21	0.52	0.64
	3 to 4	1.49	0.33	0.79	1.48	0.35	0.79	1.43	0.38	0.74	1.38	0.43	0.69	1.37	0.47	0.65
	6 to 7	1.86	0.28	0.80	1.83	0.33	0.76	1.77	0.34	0.74	1.73	0.38	0.69	1.68	0.45	0.65
	8 to 10	2.49	0.22	0.70	2.46	0.22	0.69	2.41	0.29	0.64	2.38	0.32	0.63	2.32	0.34	0.62
¾ to 2 in.	½ to 1	1.24	0.31	0.86	1.23	0.33	0.85	1.09	0.34	0.76	1.15	0.41	0.78	1.12	0.45	0.73
	3 to 4	1.41	0.29	0.85	1.40	0.31	0.85	1.35	0.34	0.82	1.29	0.38	0.76	1.28	0.44	0.74
	6 to 7	1.77	0.26	0.84	1.74	0.28	0.82	1.68	0.30	0.80	1.62	0.34	0.77	1.58	0.38	0.73
	8 to 10	2.41	0.18	0.75	2.37	0.21	0.74	2.32	0.24	0.76	2.30	0.27	0.75	2.22	0.30	0.69
¾ to 1½ in.	½ to 1	1.30	0.38	0.73	1.29	0.44	0.72	1.21	0.47	0.66	1.18	0.52	0.63	1.16	0.58	0.57
	3 to 4	1.47	0.37	0.72	1.45	0.43	0.71	1.40	0.46	0.66	1.35	0.50	0.64	1.32	0.57	0.57
	6 to 7	1.80	0.32	0.69	1.80	0.37	0.69	1.75	0.42	0.67	1.67	0.47	0.62	1.64	0.51	0.56
	8 to 10	2.48	0.26	0.63	2.45	0.29	0.62	2.40	0.32	0.60	2.31	0.38	0.58	2.27	0.40	0.54
¾ to 2 in.	½ to 1	1.22	0.36	0.79	1.22	0.40	0.79	1.18	0.44	0.75	1.10	0.47	0.70	1.07	0.52	0.65
	3 to 4	1.41	0.35	0.79	1.38	0.39	0.77	1.33	0.41	0.75	1.27	0.47	0.69	1.23	0.51	0.65
	6 to 7	1.74	0.31	0.77	1.70	0.35	0.76	1.66	0.37	0.74	1.58	0.42	0.70	1.53	0.45	0.64
	8 to 10	2.40	0.25	0.71	2.36	0.28	0.70	2.29	0.31	0.68	2.22	0.33	0.66	2.17	0.38	0.64
¾ to 3 in.	½ to 1	1.15	0.34	0.85	1.13	0.37	0.84	1.10	0.41	0.81	1.05	0.42	0.78	1.02	0.48	0.71
	3 to 4	1.33	0.33	0.84	1.30	0.37	0.83	1.25	0.39	0.79	1.21	0.43	0.77	1.18	0.47	0.72
	6 to 7	1.67	0.30	0.82	1.59	0.33	0.80	1.55	0.34	0.78	1.49	0.40	0.75	1.45	0.43	0.71
	8 to 10	2.32	0.24	0.75	2.27	0.27	0.74	2.20	0.29	0.72	2.13	0.32	0.73	2.12	0.38	0.72

TABLE XVIII.—PROPORTIONS FOR 3,000 LB. PER SQUARE INCH CONCRETE

Based on 28-day compressive strength of 6 by 12-in. cylinders.
 Proportions are expressed by volume as follows: Portland Cement: Fine Aggregate:
 Coarse Aggregate.
 Thus 1:2.6:4.6 indicates 1 part by volume of portland cement, 2.6 parts by volume of
 fine aggregate and 4.6 parts by volume of coarse aggregate.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Proportions using fine aggregate of different sizes				
		0-No. 30	0-No. 16	0-No. 8	0-No. 4	0- $\frac{3}{8}$ in.
None.....	$\frac{1}{2}$ to 1	1:1.5	1:1.7	1:2.0	1:2.3	1:2.7
	3 to 4	1:1.2	1:1.4	1:1.7	1:1.9	1:2.3
	6 to 7	1:0.9	1:1.0	1:1.2	1:1.4	1:1.6
	8 to 10	1:0.5	1:0.6	1:0.7	1:0.8	1:0.9
No. 4 to $\frac{3}{4}$ in....	$\frac{1}{2}$ to 1	1:1.3:2.7	1:1.5:2.6	1:1.7:2.5	1:1.9:2.4	1:2.3:2.1
	3 to 4	1:1.0:2.3	1:1.2:2.2	1:1.4:2.2	1:1.6:2.0	1:1.9:1.8
	6 to 7	1:0.7:1.7	1:0.8:1.7	1:0.9:1.7	1:1.1:1.6	1:1.3:1.4
	8 to 10	1:0.3:1.0	1:0.4:1.0	1:0.5:1.0	1:0.5:1.0	1:0.6:0.9
No. 4 to 1 in....	$\frac{1}{2}$ to 1	1:1.2:3.1	1:1.3:3.1	1:1.5:3.0	1:1.8:2.9	1:2.1:2.7
	3 to 4	1:0.9:2.7	1:1.1:2.6	1:1.2:2.6	1:1.4:2.5	1:1.7:2.3
	6 to 7	1:0.6:2.0	1:0.7:2.0	1:0.8:2.0	1:0.9:1.9	1:1.1:1.8
	8 to 10	1:0.3:1.2	1:0.3:1.2	1:0.4:1.2	1:0.5:1.2	1:0.6:1.2
No. 4 to 1 $\frac{1}{2}$ in..	$\frac{1}{2}$ to 1	1:1.1:3.6	1:1.2:3.5	1:1.5:3.5	1:1.7:3.4	1:2.0:3.2
	3 to 4	1:0.9:3.0	1:1.0:2.9	1:1.2:2.9	1:1.4:2.9	1:1.6:2.7
	6 to 7	1:0.6:2.2	1:0.7:2.2	1:0.8:2.2	1:0.9:2.2	1:1.1:2.1
	8 to 10	1:0.3:1.4	1:0.3:1.3	1:0.4:1.4	1:0.5:1.4	1:0.5:1.3
No. 4 to 2 in....	$\frac{1}{2}$ to 1	1:1.0:4.1	1:1.1:4.1	1:1.2:4.1	1:1.4:4.1	1:1.6:4.0
	3 to 4	1:0.8:3.4	1:0.9:3.4	1:1.0:3.5	1:1.1:3.4	1:1.3:3.4
	6 to 7	1:0.5:2.6	1:0.6:2.6	1:0.6:2.7	1:0.7:2.6	1:0.9:2.6
	8 to 10	1:0.2:1.6	1:0.3:1.6	1:0.3:1.7	1:0.4:1.7	1:0.4:1.7
$\frac{3}{8}$ to 1 in.....	$\frac{1}{2}$ to 1	1:1.4:3.1	1:1.5:3.0	1:1.8:2.9	1:2.1:2.8	1:2.4:2.6
	3 to 4	1:1.1:2.6	1:1.3:2.6	1:1.5:2.5	1:1.7:2.4	1:2.0:2.2
	6 to 7	1:0.8:2.0	1:0.8:2.0	1:1.0:1.9	1:1.1:1.9	1:1.3:1.8
	8 to 10	1:0.4:1.2	1:0.4:1.2	1:0.5:1.2	1:0.6:1.2	1:0.7:1.1
$\frac{3}{8}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:1.4:3.5	1:1.5:3.4	1:1.7:3.4	1:2.0:3.3	1:2.3:3.1
	3 to 4	1:1.1:3.0	1:1.2:2.9	1:1.4:2.9	1:1.6:2.8	1:1.9:2.6
	6 to 7	1:0.8:2.2	1:0.8:2.2	1:1.0:2.2	1:1.1:2.1	1:1.3:2.0
	8 to 10	1:0.4:1.4	1:0.4:1.4	1:0.5:1.4	1:0.6:1.3	1:0.7:1.3
$\frac{3}{8}$ to 2 in.....	$\frac{1}{2}$ to 1	1:1.3:4.0	1:1.4:4.0	1:1.6:4.0	1:1.9:3.9	1:2.1:3.8
	3 to 4	1:1.0:3.4	1:1.2:3.4	1:1.3:3.3	1:1.5:3.3	1:1.7:3.2
	6 to 7	1:0.7:2.6	1:0.8:2.5	1:0.9:2.6	1:1.0:2.6	1:1.1:2.5
	8 to 10	1:0.4:1.6	1:0.4:1.6	1:0.5:1.6	1:0.5:1.6	1:0.6:1.6
$\frac{3}{4}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:1.6:3.2	1:1.8:3.2	1:2.1:3.2	1:2.4:3.1	1:2.7:2.9
	3 to 4	1:1.3:2.7	1:1.5:2.7	1:1.7:2.7	1:2.0:2.6	1:2.3:2.5
	6 to 7	1:0.9:2.0	1:1.0:2.1	1:1.2:2.0	1:1.4:2.0	1:1.5:1.8
	8 to 10	1:0.5:1.2	1:0.5:1.3	1:0.6:1.3	1:0.7:1.3	1:0.8:1.2
$\frac{3}{4}$ to 2 in.....	$\frac{1}{2}$ to 1	1:1.6:3.7	1:1.8:3.7	1:2.0:3.7	1:2.4:3.6	1:2.6:3.5
	3 to 4	1:1.3:3.1	1:1.5:3.1	1:1.6:3.1	1:1.9:3.1	1:2.2:3.0
	6 to 7	1:0.9:2.4	1:1.1:2.4	1:1.1:2.4	1:1.3:2.4	1:1.5:2.3
	8 to 10	1:0.5:1.5	1:0.5:1.5	1:0.6:1.5	1:0.7:1.5	1:0.8:1.5
$\frac{3}{4}$ to 3 in.....	$\frac{1}{2}$ to 1	1:1.6:4.2	1:1.8:4.2	1:2.0:4.2	1:2.3:4.1	1:2.6:4.0
	3 to 4	1:1.3:3.5	1:1.5:3.6	1:1.6:3.6	1:1.9:3.6	1:2.1:3.5
	6 to 7	1:0.9:2.6	1:1.0:2.6	1:1.1:2.6	1:1.3:2.6	1:1.4:2.6
	8 to 10	1:0.5:1.6	1:0.5:1.6	1:0.6:1.7	1:0.7:1.7	1:0.8:1.7

TABLE XIX.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF 3,000 LB. PER SQUARE INCH CONCRETE

The volume of cement is expressed in barrels and of aggregates in cubic yards.
 F = fine aggregate; C = coarse aggregate.
 Quantities are net, no allowance being made for waste; for average conditions, the following additions are suggested: Cement, 2 per cent; fine aggregate, 10 per cent; coarse aggregate, 5 per cent.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Quantities of materials using fine aggregate of different sizes														
		0-No. 30			0-No. 16			0-No. 8			0-No. 4			0-3/8 in.		
		Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement
		F	C		F	C		F	C		F	C		F	C	
None.....	1/2 to 1	3.08	0.68	....	2.96	0.74	....	2.65	0.78	....	2.34	0.80	....	2.14	0.86	....
	3 to 4	3.61	0.64	....	3.31	0.69	....	2.93	0.74	....	2.66	0.75	....	2.37	0.81	....
	6 to 7	3.99	0.53	....	3.79	0.56	....	3.57	0.63	....	3.18	0.66	....	2.93	0.69	....
	8 to 10	4.77	0.35	....	4.63	0.41	....	4.34	0.45	....	3.93	0.47	....	3.79	0.50	....
No. 4 to 3/4 in.	1/2 to 1	1.75	0.34	0.70	1.73	0.38	0.66	1.69	0.42	0.63	1.63	0.46	0.58	1.59	0.54	0.49
	3 to 4	2.00	0.30	0.68	1.97	0.35	0.64	1.93	0.40	0.63	1.86	0.44	0.55	1.86	0.52	0.49
	6 to 7	2.48	0.26	0.62	2.46	0.29	0.62	2.38	0.32	0.60	2.37	0.39	0.56	2.35	0.45	0.49
	8 to 10	3.46	0.15	0.51	3.44	0.20	0.51	3.38	0.25	0.50	3.34	0.25	0.49	3.31	0.29	0.44
No. 4 to 1 in....	1/2 to 1	1.68	0.30	0.77	1.65	0.32	0.76	1.60	0.36	0.71	1.55	0.41	0.66	1.53	0.47	0.61
	3 to 4	1.88	0.25	0.75	1.86	0.30	0.72	1.83	0.32	0.70	1.78	0.37	0.66	1.76	0.44	0.60
	6 to 7	2.39	0.21	0.71	2.38	0.25	0.70	2.32	0.27	0.69	2.27	0.30	0.64	2.26	0.37	0.60
	8 to 10	3.32	0.15	0.59	3.30	0.15	0.59	3.25	0.19	0.58	3.21	0.24	0.57	3.18	0.28	0.56
No. 4 to 1 1/2 in.	1/2 to 1	1.58	0.23	0.84	1.55	0.28	0.80	1.50	0.33	0.78	1.46	0.37	0.73	1.46	0.43	0.69
	3 to 4	1.80	0.24	0.80	1.78	0.26	0.76	1.73	0.31	0.74	1.68	0.35	0.72	1.67	0.40	0.67
	6 to 7	2.30	0.20	0.75	2.27	0.24	0.74	2.21	0.26	0.72	2.15	0.29	0.70	2.12	0.35	0.66
	8 to 10	3.19	0.14	0.66	3.17	0.14	0.61	3.09	0.18	0.64	3.04	0.22	0.63	3.02	0.22	0.58
No. 4 to 2 in....	1/2 to 1	1.50	0.22	0.91	1.49	0.24	0.90	1.43	0.25	0.87	1.38	0.29	0.84	1.38	0.33	0.82
	3 to 4	1.73	0.20	0.87	1.71	0.23	0.86	1.65	0.24	0.85	1.60	0.26	0.81	1.60	0.31	0.80
	6 to 7	2.18	0.16	0.84	2.14	0.19	0.82	2.06	0.18	0.82	2.01	0.21	0.77	2.01	0.27	0.77
	8 to 10	3.12	0.09	0.74	3.09	0.14	0.73	3.04	0.14	0.76	2.94	0.17	0.74	2.94	0.17	0.74
3/8 to 1 in.....	1/2 to 1	1.69	0.35	0.77	1.65	0.37	0.73	1.60	0.43	0.69	1.54	0.45	0.64	1.51	0.54	0.58
	3 to 4	1.91	0.31	0.73	1.88	0.36	0.72	1.82	0.40	0.67	1.78	0.45	0.63	1.73	0.51	0.56
	6 to 7	2.40	0.28	0.71	2.36	0.28	0.70	2.31	0.34	0.65	2.26	0.37	0.64	2.19	0.42	0.58
	8 to 10	3.23	0.19	0.57	3.21	0.19	0.57	3.15	0.23	0.56	3.00	0.27	0.53	2.93	0.30	0.48
3/8 to 1 1/2 in....	1/2 to 1	1.57	0.32	0.81	1.55	0.34	0.78	1.50	0.38	0.75	1.45	0.43	0.71	1.43	0.49	0.66
	3 to 4	1.81	0.30	0.81	1.78	0.32	0.76	1.73	0.36	0.74	1.68	0.40	0.70	1.63	0.46	0.63
	6 to 7	2.30	0.20	0.75	2.26	0.27	0.74	2.20	0.33	0.72	2.15	0.35	0.67	2.08	0.35	0.62
	8 to 10	2.97	0.18	0.61	2.94	0.17	0.61	2.88	0.21	0.60	2.87	0.26	0.60	2.78	0.30	0.55
3/8 to 2 in.....	1/2 to 1	1.49	0.29	0.88	1.48	0.32	0.88	1.42	0.34	0.84	1.36	0.38	0.77	1.34	0.42	0.75
	3 to 4	1.73	0.26	0.87	1.70	0.30	0.86	1.63	0.31	0.80	1.58	0.35	0.77	1.55	0.39	0.73
	6 to 7	2.18	0.23	0.84	2.12	0.25	0.79	2.05	0.27	0.79	2.01	0.30	0.77	1.93	0.31	0.72
	8 to 10	2.98	0.18	0.71	2.99	0.18	0.71	2.90	0.21	0.69	2.93	0.22	0.69	2.84	0.25	0.67
3/4 to 1 1/2 in....	1/2 to 1	1.55	0.37	0.73	1.52	0.40	0.72	1.48	0.46	0.70	1.41	0.50	0.65	1.38	0.55	0.59
	3 to 4	1.79	0.34	0.71	1.75	0.39	0.70	1.71	0.43	0.68	1.63	0.48	0.63	1.59	0.54	0.59
	6 to 7	2.29	0.30	0.68	2.24	0.33	0.70	2.17	0.39	0.64	2.08	0.43	0.62	2.03	0.45	0.54
	8 to 10	3.03	0.22	0.54	3.01	0.22	0.58	2.93	0.26	0.56	2.90	0.30	0.56	2.83	0.34	0.51
3/4 to 2 in.....	1/2 to 1	1.47	0.35	0.80	1.44	0.38	0.79	1.40	0.41	0.77	1.34	0.48	0.71	1.29	0.50	0.67
	3 to 4	1.70	0.33	0.78	1.66	0.37	0.76	1.62	0.38	0.74	1.53	0.43	0.70	1.50	0.49	0.67
	6 to 7	2.16	0.29	0.77	2.08	0.34	0.74	2.04	0.33	0.73	1.92	0.37	0.68	1.90	0.42	0.65
	8 to 10	2.97	0.22	0.66	2.97	0.22	0.66	2.81	0.25	0.62	2.74	0.28	0.62	2.74	0.23	0.62
3/4 to 3 in.....	1/2 to 1	1.39	0.33	0.86	1.35	0.36	0.84	1.30	0.38	0.81	1.25	0.42	0.76	1.21	0.46	0.71
	3 to 4	1.60	0.31	0.83	1.55	0.34	0.83	1.52	0.36	0.81	1.46	0.41	0.78	1.42	0.44	0.73
	6 to 7	2.03	0.27	0.78	1.98	0.29	0.76	1.94	0.32	0.75	1.87	0.36	0.72	1.83	0.38	0.70
	8 to 10	2.87	0.21	0.68	2.85	0.21	0.67	2.75	0.24	0.69	2.69	0.28	0.68	2.64	0.31	0.66

TABLE XX.—PROPORTIONS FOR 3,500 LB. PER SQUARE INCH CONCRETE

Based on 28-day compressive strength of 6 by 12-in. cylinders.

Proportions are expressed by volume as follows: Portland Cement:Fine Aggregate: Coarse Aggregate.

Thus 1:2.6:4.6 indicates 1 part by volume of portland cement, 2.6 parts by volume of fine aggregate and 4.6 parts by volume of coarse aggregate.

See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Proportions using fine aggregate of different sizes				
		0-No. 30	0-No. 16	0-No. 8	0-No. 4	0- $\frac{3}{8}$ in.
None.....	$\frac{1}{2}$ to 1	1:1.2	1:1.4	1:1.6	1:1.9	1:2.2
	3 to 4	1:1.0	1:1.1	1:1.3	1:1.5	1:1.8
	6 to 7	1:0.6	1:0.8	1:0.9	1:1.0	1:1.2
	8 to 10	1:0.3	1:0.4	1:0.4	1:0.5	1:0.6
No. 4 to $\frac{3}{4}$ in....	$\frac{1}{2}$ to 1	1:1.0:2.2	1:1.1:2.2	1:1.3:2.1	1:1.5:2.0	1:1.8:1.8
	3 to 4	1:0.8:1.9	1:0.9:1.9	1:1.0:1.8	1:1.2:1.7	1:1.4:1.5
	6 to 7	1:0.5:1.3	1:0.6:1.4	1:0.6:1.3	1:0.8:1.3	1:0.9:1.2
	8 to 10	1:0.2:0.7	1:0.2:0.7	1:0.3:0.7	1:0.3:0.7	1:0.4:0.6
No. 4 to 1 in....	$\frac{1}{2}$ to 1	1:0.9:2.6	1:1.0:2.6	1:1.2:2.5	1:1.4:2.4	1:1.6:2.3
	3 to 4	1:0.7:2.2	1:0.8:2.2	1:0.9:2.2	1:1.1:2.1	1:1.3:2.0
	6 to 7	1:0.4:1.5	1:0.5:1.5	1:0.6:1.5	1:0.6:1.5	1:0.8:1.4
	8 to 10	1:0.2:0.8	1:0.2:0.8	1:0.2:0.8	1:0.3:0.8	1:0.3:0.8
No. 4 to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:0.9:2.9	1:1.0:2.9	1:1.1:2.9	1:1.3:2.8	1:1.5:2.7
	3 to 4	1:0.7:2.5	1:0.8:2.4	1:0.9:2.4	1:1.0:2.4	1:1.2:2.3
	6 to 7	1:0.4:1.8	1:0.5:1.7	1:0.5:1.8	1:0.6:1.7	1:0.7:1.7
	8 to 10	1:0.2:0.9	1:0.2:0.9	1:0.2:0.9	1:0.2:0.9	1:0.3:0.9
No. 4 to 2 in....	$\frac{1}{2}$ to 1	1:0.7:3.3	1:0.8:3.3	1:0.9:3.4	1:1.0:3.3	1:1.2:3.3
	3 to 4	1:0.6:2.8	1:0.6:2.8	1:0.7:2.8	1:0.8:2.8	1:1.0:2.8
	6 to 7	1:0.3:2.0	1:0.4:2.0	1:0.4:2.0	1:0.5:2.0	1:0.6:2.0
	8 to 10	1:0.1:1.0	1:0.1:1.0	1:0.2:1.0	1:0.2:1.0	1:0.2:1.0
$\frac{3}{8}$ to 1 in.....	$\frac{1}{2}$ to 1	1:1.1:2.5	1:1.2:2.5	1:1.4:2.5	1:1.6:2.3	1:1.8:2.2
	3 to 4	1:0.8:2.1	1:0.9:2.1	1:1.1:2.1	1:1.3:2.0	1:1.5:1.9
	6 to 7	1:0.5:1.5	1:0.6:1.5	1:0.7:1.5	1:0.8:1.4	1:0.9:1.4
	8 to 10	1:0.2:0.8	1:0.2:0.8	1:0.3:0.8	1:0.3:0.8	1:0.4:0.7
$\frac{3}{8}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:1.0:2.8	1:1.2:2.8	1:1.3:2.8	1:1.6:2.7	1:1.8:2.6
	3 to 4	1:0.8:2.4	1:0.9:2.4	1:1.1:2.4	1:1.2:2.3	1:1.5:2.3
	6 to 7	1:0.5:1.7	1:0.6:1.7	1:0.7:1.7	1:0.8:1.7	1:0.9:1.6
	8 to 10	1:0.2:0.8	1:0.2:0.8	1:0.3:0.8	1:0.3:0.8	1:0.4:0.8
$\frac{3}{8}$ to 2 in.....	$\frac{1}{2}$ to 1	1:1.0:3.2	1:1.1:3.2	1:1.2:3.2	1:1.4:3.2	1:1.6:3.1
	3 to 4	1:0.8:2.7	1:0.8:2.7	1:1.0:2.7	1:1.1:2.7	1:1.3:2.7
	6 to 7	1:0.5:1.9	1:0.5:1.9	1:0.6:2.0	1:0.7:2.0	1:0.8:1.9
	8 to 10	1:0.2:0.9	1:0.2:1.0	1:0.2:1.0	1:0.3:1.0	1:0.3:1.0
$\frac{3}{4}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:1.3:2.6	1:1.4:2.7	1:1.6:2.6	1:1.9:2.6	1:2.2:2.4
	3 to 4	1:1.0:2.2	1:1.2:2.3	1:1.3:2.2	1:1.5:2.2	1:1.8:2.1
	6 to 7	1:0.7:1.6	1:0.7:1.6	1:0.9:1.6	1:1.0:1.6	1:1.2:1.6
	8 to 10	1:0.3:0.8	1:0.3:0.8	1:0.4:0.8	1:0.4:0.8	1:0.5:0.8
$\frac{3}{4}$ to 2 in.....	$\frac{1}{2}$ to 1	1:1.2:3.0	1:1.4:3.1	1:1.6:3.1	1:1.8:3.1	1:2.1:3.0
	3 to 4	1:1.0:2.5	1:1.1:2.6	1:1.2:2.6	1:1.5:2.6	1:1.7:2.5
	6 to 7	1:0.6:1.8	1:0.7:1.8	1:0.8:1.9	1:0.9:1.9	1:1.1:1.9
	8 to 10	1:0.3:0.9	1:0.3:0.9	1:0.3:0.9	1:0.4:0.9	1:0.5:0.9
$\frac{3}{4}$ to 3 in.....	$\frac{1}{2}$ to 1	1:1.2:3.4	1:1.3:3.4	1:1.5:3.4	1:1.7:3.3	1:2.0:3.3
	3 to 4	1:1.0:2.8	1:1.1:2.8	1:1.2:2.8	1:1.4:2.8	1:1.6:2.8
	6 to 7	1:0.6:2.0	1:0.7:2.0	1:0.8:2.0	1:0.9:2.0	1:1.0:2.0
	8 to 10	1:0.3:1.0	1:0.3:1.0	1:0.3:1.0	1:0.4:1.0	1:0.4:1.0

TABLE XXI.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF 3,500 LB. PER SQUARE INCH CONCRETE

The volume of cement is expressed in barrels and of aggregates in cubic yards.

F = fine aggregate; C = coarse aggregate.

Quantities are net, no allowance being made for waste; for average conditions, the following additions are suggested: Cement, 2 per cent; fine aggregate, 10 per cent; coarse aggregate, 5 per cent.

See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Quantities of materials using fine aggregate of different sizes														
		0-No. 30			0-No. 16			0-No. 8			0-No. 4			0-¾ in.		
		Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement
		F	C		F	C		F	C		F	C		F	C	
None.....	½ to 1	3.58	0.64	....	3.38	0.70	....	3.11	0.74	....	2.71	0.76	....	2.48	0.81	....
	3 to 4	3.90	0.58	....	3.83	0.62	....	3.51	0.68	....	3.13	0.70	....	2.81	0.75	....
	6 to 7	4.82	0.43	....	4.34	0.52	....	4.12	0.55	....	3.79	0.56	....	3.46	0.61	....
	8 to 10	....	....	....	5.00	0.30	....	4.95	0.29	....	4.48	0.33	....	4.37	0.30	....
No. 4 to ¾ in.	½ to 1	2.08	0.31	0.68	2.06	0.34	0.67	2.01	0.39	0.63	1.91	0.42	0.57	1.92	0.51	0.51
	3 to 4	2.38	0.28	0.67	2.36	0.31	0.66	2.52	0.37	0.67	2.25	0.40	0.57	2.22	0.46	0.49
	6 to 7	3.08	0.23	0.69	3.02	0.27	0.63	2.96	0.26	0.57	2.88	0.34	0.56	2.83	0.38	0.50
	8 to 10	4.02	0.12	0.42	3.96	0.12	0.41	3.89	0.17	0.40	3.83	0.17	0.40	3.79	0.22	0.34
No. 4 to 1 in.	½ to 1	1.95	0.26	0.75	1.93	0.29	0.74	1.90	0.34	0.70	1.84	0.38	0.65	1.84	0.43	0.63
	3 to 4	2.27	0.24	0.74	2.25	0.27	0.73	2.18	0.29	0.71	2.15	0.35	0.67	2.10	0.40	0.62
	6 to 7	2.93	0.17	0.65	2.89	0.21	0.64	2.79	0.25	0.62	2.74	0.24	0.61	2.67	0.32	0.55
	8 to 10	3.88	0.11	0.46	3.82	0.11	0.45	3.79	0.11	0.45	3.68	0.16	0.44	3.67	0.16	0.43
No. 4 to 1½ in.	½ to 1	1.85	0.25	0.79	1.85	0.27	0.79	1.80	0.29	0.77	1.70	0.33	0.70	1.73	0.38	0.69
	3 to 4	2.14	0.22	0.79	2.11	0.25	0.75	2.05	0.27	0.73	1.97	0.29	0.70	1.98	0.35	0.67
	6 to 7	2.76	0.22	0.74	2.70	0.20	0.68	2.59	0.19	0.69	2.58	0.23	0.65	2.58	0.27	0.65
	8 to 10	3.79	0.11	0.50	3.69	0.11	0.49	3.67	0.11	0.49	3.72	0.11	0.50	3.80	0.17	0.51
No. 4 to 2 in.	½ to 1	1.79	0.19	0.87	1.77	0.21	0.86	1.71	0.23	0.86	1.68	0.25	0.87	1.65	0.29	0.81
	3 to 4	2.04	0.18	0.84	2.00	0.18	0.83	1.95	0.20	0.81	1.92	0.23	0.80	1.91	0.28	0.79
	6 to 7	2.62	0.12	0.78	2.60	0.15	0.77	2.52	0.15	0.75	2.50	0.19	0.74	2.50	0.22	0.74
	8 to 10	3.81	0.06	0.56	3.75	0.06	0.56	3.72	0.11	0.55	3.68	0.11	0.54	3.76	0.11	0.56
¾ to 1 in.	½ to 1	2.02	0.33	0.75	1.94	0.34	0.72	1.88	0.39	0.69	1.85	0.44	0.63	1.79	0.48	0.58
	3 to 4	2.28	0.27	0.71	2.24	0.30	0.70	2.18	0.35	0.68	2.14	0.41	0.63	2.05	0.45	0.58
	6 to 7	2.86	0.21	0.64	2.84	0.25	0.63	2.76	0.29	0.61	2.74	0.32	0.57	2.66	0.35	0.55
	8 to 10	3.88	0.11	0.46	3.82	0.11	0.45	3.79	0.17	0.45	3.68	0.16	0.44	3.67	0.22	0.38
¾ to 1½ in.	½ to 1	1.88	0.28	0.78	1.85	0.33	0.77	1.79	0.34	0.74	1.74	0.41	0.70	1.69	0.45	0.65
	3 to 4	2.16	0.26	0.77	2.10	0.28	0.75	2.04	0.33	0.73	1.98	0.35	0.67	1.93	0.43	0.66
	6 to 7	2.72	0.20	0.68	2.66	0.24	0.67	2.59	0.27	0.65	2.56	0.30	0.64	2.52	0.34	0.60
	8 to 10	3.79	0.11	0.45	3.69	0.11	0.44	3.67	0.16	0.43	3.40	0.15	0.40	3.31	0.20	0.39
¾ to 2 in.	½ to 1	1.78	0.26	0.84	1.75	0.28	0.83	1.69	0.30	0.80	1.63	0.36	0.77	1.59	0.38	0.73
	3 to 4	2.03	0.24	0.81	1.98	0.23	0.79	1.93	0.29	0.77	1.91	0.31	0.76	1.84	0.35	0.73
	6 to 7	2.58	0.19	0.73	2.54	0.19	0.71	2.49	0.22	0.74	2.47	0.26	0.73	2.40	0.28	0.68
	8 to 10	3.80	0.11	0.51	3.73	0.11	0.55	3.64	0.11	0.54	3.68	0.16	0.54	3.56	0.16	0.53
¾ to 1½ in.	½ to 1	1.84	0.35	0.71	1.82	0.38	0.73	1.77	0.42	0.68	1.68	0.47	0.65	1.65	0.54	0.59
	3 to 4	2.13	0.32	0.69	2.09	0.37	0.71	2.02	0.39	0.66	1.85	0.41	0.60	1.89	0.50	0.59
	6 to 7	2.68	0.28	0.64	2.63	0.27	0.62	2.56	0.34	0.61	2.49	0.37	0.59	2.45	0.44	0.58
	8 to 10	3.79	0.17	0.45	3.69	0.16	0.43	3.67	0.22	0.43	3.72	0.22	0.44	3.66	0.27	0.43
¾ to 2 in.	½ to 1	1.76	0.31	0.78	1.72	0.36	0.79	1.67	0.40	0.77	1.58	0.42	0.72	1.55	0.48	0.69
	3 to 4	2.01	0.30	0.74	1.95	0.31	0.75	1.92	0.34	0.74	1.84	0.41	0.71	1.80	0.45	0.67
	6 to 7	2.58	0.23	0.69	2.54	0.26	0.68	2.48	0.29	0.70	2.40	0.32	0.68	2.35	0.38	0.66
	8 to 10	3.78	0.17	0.50	3.73	0.17	0.50	3.63	0.16	0.48	3.59	0.21	0.48	3.49	0.26	0.46
¾ to 3 in.	½ to 1	1.67	0.30	0.84	1.61	0.31	0.81	1.57	0.35	0.79	1.51	0.38	0.74	1.47	0.43	0.72
	3 to 4	1.91	0.28	0.79	1.86	0.30	0.77	1.93	0.34	0.80	1.76	0.36	0.73	1.71	0.40	0.71
	6 to 7	2.48	0.22	0.74	2.43	0.25	0.72	2.37	0.28	0.70	2.30	0.31	0.68	2.25	0.33	0.67
	8 to 10	3.64	0.16	0.54	3.57	0.16	0.53	3.52	0.16	0.52	3.46	0.20	0.51	3.38	0.20	0.50

TABLE XXII.—PROPORTIONS FOR 4,000 LB. PER SQUARE INCH CONCRETE

Based on 28-day compressive strength of 6 by 12-in. cylinders.
 Proportions are expressed by volume as follows: Portland Cement:Fine Aggregate:
 Coarse Aggregate.
 Thus 1:2.6:4.6 indicates 1 part by volume of portland cement, 2.6 parts by volume of
 fine aggregate and 4.6 parts by volume of coarse aggregate.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Proportions using fine aggregate of different sizes				
		0-No. 30	0-No. 16	0-No. 8	0-No. 4	0- $\frac{3}{8}$ in.
None.....	$\frac{1}{2}$ to 1	1:0.9	1:1.1	1:1.2	1:1.5	1:1.7
	3 to 4	1:0.7	1:0.9	1:1.0	1:1.2	1:1.4
	6 to 7	1:0.4	1:0.5	1:0.6	1:0.7	1:0.7
	8 to 10	1:0.1	1:0.2	1:0.2	1:0.2	1:0.3
No. 4 to $\frac{3}{4}$ in....	$\frac{1}{2}$ to 1	1:0.8:1.8	1:0.9:1.8	1:1.0:1.8	1:1.2:1.7	1:1.4:1.5
	3 to 4	1:0.6:1.5	1:0.6:1.4	1:0.8:1.5	1:0.9:1.4	1:1.1:1.3
	6 to 7	1:0.3:0.9	1:0.4:1.0	1:0.4:0.9	1:0.5:0.9	1:0.6:0.9
	8 to 10	1:0.1:0.3	1:0.1:0.3	1:0.1:0.3	1:0.1:0.3	1:0.2:0.3
No. 4 to 1 in....	$\frac{1}{2}$ to 1	1:0.7:2.1	1:0.8:2.1	1:0.9:2.1	1:1.0:2.0	1:1.2:1.9
	3 to 4	1:0.5:1.7	1:0.6:1.6	1:0.7:1.7	1:0.8:1.7	1:0.9:1.6
	6 to 7	1:0.3:1.1	1:0.3:1.1	1:0.4:1.1	1:0.4:1.1	1:0.5:1.1
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4
No. 4 to 1 $\frac{1}{2}$ in..	$\frac{1}{2}$ to 1	1:0.6:2.4	1:0.7:2.4	1:0.8:2.4	1:1.0:2.3	1:1.1:2.2
	3 to 4	1:0.5:2.0	1:0.5:1.9	1:0.6:2.0	1:0.7:1.9	1:0.9:1.9
	6 to 7	1:0.3:1.2	1:0.3:1.2	1:0.3:1.2	1:0.4:1.2	1:0.4:1.2
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4
No. 4 to 2 in....	$\frac{1}{2}$ to 1	1:0.5:2.7	1:0.6:2.7	1:0.7:2.7	1:0.8:2.7	1:0.9:2.8
	3 to 4	1:0.4:2.2	1:0.4:2.2	1:0.5:2.3	1:0.6:2.3	1:0.7:2.3
	6 to 7	1:0.2:1.4	1:0.2:1.4	1:0.3:1.4	1:0.3:1.5	1:0.3:1.4
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.1:0.5	1:0.1:0.5	1:0.1:0.5
$\frac{3}{8}$ to 1 in.....	$\frac{1}{2}$ to 1	1:0.8:2.1	1:0.9:2.0	1:1.0:2.0	1:1.2:1.9	1:1.4:1.8
	3 to 4	1:0.6:1.7	1:0.7:1.7	1:0.8:1.6	1:0.9:1.6	1:1.1:1.5
	6 to 7	1:0.3:1.1	1:0.4:1.1	1:0.4:1.0	1:0.5:1.0	1:0.6:1.0
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.2:0.4
$\frac{3}{8}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:0.8:2.3	1:0.9:2.3	1:1.0:2.3	1:1.2:2.3	1:1.4:2.2
	3 to 4	1:0.6:1.9	1:0.7:1.9	1:0.8:1.9	1:0.9:1.9	1:1.1:1.8
	6 to 7	1:0.3:1.2	1:0.4:1.2	1:0.4:1.2	1:0.5:1.2	1:0.6:1.2
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.1:0.4	1:0.2:0.4
$\frac{3}{8}$ to 2 in.....	$\frac{1}{2}$ to 1	1:0.7:2.6	1:0.8:2.6	1:0.9:2.6	1:1.0:2.6	1:1.2:2.6
	3 to 4	1:0.6:2.1	1:0.6:2.2	1:0.7:2.2	1:0.8:2.2	1:1.0:2.2
	6 to 7	1:0.3:1.4	1:0.3:1.4	1:0.4:1.4	1:0.4:1.4	1:0.5:1.4
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.1:0.5	1:0.1:0.4	1:0.1:0.5
$\frac{3}{4}$ to 1 $\frac{1}{2}$ in....	$\frac{1}{2}$ to 1	1:1.0:2.2	1:1.1:2.2	1:1.3:2.2	1:1.5:2.1	1:1.7:2.0
	3 to 4	1:0.8:1.8	1:0.9:1.8	1:1.0:1.8	1:1.2:1.8	1:1.3:1.7
	6 to 7	1:0.4:1.1	1:0.5:1.1	1:0.6:1.2	1:0.7:1.1	1:0.8:1.1
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.2:0.4	1:0.2:0.4	1:0.2:0.4
$\frac{3}{4}$ to 2 in.....	$\frac{1}{2}$ to 1	1:0.9:2.5	1:1.0:2.5	1:1.2:2.5	1:1.4:2.5	1:1.6:2.5
	3 to 4	1:0.7:2.0	1:0.8:2.1	1:0.9:2.1	1:1.1:2.1	1:1.3:2.1
	6 to 7	1:0.4:1.3	1:0.5:1.3	1:0.5:1.4	1:0.6:1.4	1:0.7:1.3
	8 to 10	1:0.1:0.4	1:0.1:0.4	1:0.2:0.4	1:0.2:0.4	1:0.2:0.4
$\frac{3}{4}$ to 3 in.....	$\frac{1}{2}$ to 1	1:0.9:2.7	1:1.0:2.7	1:1.2:2.8	1:1.3:2.7	1:1.5:2.7
	3 to 4	1:0.7:2.2	1:0.8:2.3	1:0.9:2.3	1:1.0:2.3	1:1.2:2.2
	6 to 7	1:0.4:1.4	1:0.4:1.4	1:0.5:1.5	1:0.6:1.5	1:0.7:1.5
	8 to 10	1:0.1:0.5	1:0.1:0.5	1:0.1:0.5	1:0.2:0.5	1:0.2:0.5

TABLE XXIII.—QUANTITIES OF MATERIALS FOR 1 CU. YD. OF 4,000 LB. PER SQUARE INCH CONCRETE

The volume of cement is expressed in barrels and of aggregates in cubic yards.
 F = fine aggregate; C = coarse aggregate.
 Quantities are net, no allowance being made for waste; for average conditions, the following additions are suggested: Cement, 2 per cent; fine aggregate, 10 per cent; coarse aggregate, 5 per cent.
 See "Summary of Precautions to be Observed in Using Tables."

Size of coarse aggregate	Slump, inches	Quantities of materials using fine aggregate of different sizes														
		0-No. 30			0-No. 16			0-No. 8			0-No. 4			0-¾ in.		
		Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement	Aggregate		Cement
		F	C		F	C		F	C		F	C		F	C	
None.....	½ to 1	4.21	0.56	....	3.91	0.65	....	3.75	0.79	....	3.19	0.71	....	2.96	0.75	....
	3 to 4	4.64	0.48	....	4.25	0.57	....	4.03	0.60	....	3.57	0.64	....	3.27	0.68	....
	6 to 7	5.05	0.30	....	5.21	0.39	....	4.89	0.44	....	4.36	0.45	....	4.41	0.46	....
	8 to 10	....	....	....	....	....	....	....	....	....	....	....	....	4.78	0.21	....
No. 4 to ¾ in.	½ to 1	2.46	0.29	0.65	2.44	0.32	0.65	2.39	0.35	0.64	2.33	0.41	0.59	2.30	0.48	0.51
	3 to 4	2.86	0.25	0.64	2.80	0.25	0.58	2.54	0.32	0.61	2.64	0.35	0.55	2.61	0.42	0.50
	6 to 7	3.68	0.16	0.49	3.67	0.22	0.54	3.62	0.21	0.48	3.56	0.26	0.48	3.54	0.23	0.34
	8 to 10	4.79	0.06	0.23	4.79	0.07	0.23	4.77	0.08	0.23	4.76	0.10	0.23	4.74	0.11	0.22
No. 4 to 1 in....	½ to 1	2.36	0.24	0.73	2.32	0.27	0.72	2.27	0.30	0.71	2.21	0.33	0.65	2.18	0.39	0.61
	3 to 4	2.71	0.20	0.68	2.65	0.24	0.63	2.58	0.27	0.65	2.56	0.30	0.64	2.54	0.34	0.60
	6 to 7	3.59	0.16	0.58	3.58	0.16	0.58	3.51	0.21	0.57	3.46	0.20	0.56	3.48	0.26	0.57
	8 to 10	4.79	0.05	0.25	4.76	0.05	0.26	4.73	0.07	0.26	4.70	0.08	0.26	4.69	0.09	0.26
No. 4 to 1½ in.	½ to 1	2.25	0.20	0.80	2.21	0.23	0.78	2.15	0.25	0.76	2.03	0.30	0.69	2.05	0.33	0.67
	3 to 4	2.56	0.19	0.76	2.54	0.19	0.71	2.46	0.22	0.73	2.43	0.25	0.68	2.42	0.32	0.68
	6 to 7	3.48	0.15	0.62	3.47	0.15	0.62	3.39	0.15	0.60	3.34	0.20	0.59	3.34	0.20	0.59
	8 to 10	4.69	0.04	0.28	4.69	0.05	0.28	4.69	0.06	0.29	4.67	0.07	0.29	4.67	0.08	0.29
No. 4 to 2 in....	½ to 1	2.14	0.16	0.86	2.10	0.19	0.84	2.03	0.21	0.81	2.00	0.24	0.80	1.91	0.26	0.79
	3 to 4	2.47	0.15	0.80	2.45	0.15	0.80	2.37	0.18	0.81	2.33	0.21	0.79	2.31	0.24	0.78
	6 to 7	3.36	0.10	0.70	3.33	0.10	0.69	3.24	0.14	0.67	3.19	0.14	0.71	3.20	0.14	0.66
	8 to 10	4.69	0.03	0.31	4.68	0.03	0.30	4.67	0.04	0.32	4.61	0.04	0.33	4.54	0.05	0.33
¾ to 1 in.....	½ to 1	2.36	0.29	0.73	2.32	0.31	0.69	2.26	0.33	0.67	2.22	0.39	0.62	2.13	0.44	0.57
	3 to 4	2.65	0.24	0.67	2.62	0.27	0.66	2.58	0.31	0.61	2.54	0.34	0.60	2.48	0.40	0.55
	6 to 7	3.42	0.15	0.56	3.39	0.20	0.55	3.33	0.20	0.49	3.30	0.24	0.49	3.23	0.29	0.48
	8 to 10	4.79	0.06	0.26	4.76	0.07	0.25	4.73	0.08	0.26	4.70	0.10	0.25	4.69	0.12	0.24
¾ to 1½ in....	½ to 1	2.26	0.27	0.77	2.20	0.29	0.75	2.14	0.32	0.73	2.08	0.37	0.71	2.00	0.41	0.65
	3 to 4	2.54	0.23	0.71	2.51	0.26	0.71	2.48	0.29	0.70	2.42	0.32	0.68	2.36	0.38	0.63
	6 to 7	3.24	0.14	0.58	3.17	0.19	0.56	3.16	0.19	0.56	3.10	0.23	0.55	3.13	0.28	0.56
	8 to 10	4.69	0.06	0.28	4.69	0.07	0.28	4.69	0.08	0.28	4.67	0.09	0.28	4.67	0.11	0.28
¾ to 2 in.....	½ to 1	2.14	0.22	0.82	2.08	0.25	0.80	2.01	0.27	0.77	1.98	0.29	0.76	1.92	0.34	0.74
	3 to 4	2.46	0.22	0.76	2.42	0.21	0.79	2.34	0.24	0.76	2.31	0.27	0.75	2.22	0.33	0.72
	6 to 7	3.14	0.14	0.65	3.07	0.14	0.64	3.02	0.18	0.63	3.02	0.18	0.63	2.98	0.22	0.62
	8 to 10	4.69	0.05	0.30	4.68	0.06	0.30	4.67	0.07	0.32	4.61	0.08	0.31	4.54	0.08	0.31
¾ to 1½ in....	½ to 1	2.23	0.33	0.72	2.18	0.35	0.71	2.12	0.41	0.69	2.01	0.45	0.62	1.95	0.49	0.58
	3 to 4	2.53	0.30	0.68	2.49	0.33	0.66	2.44	0.36	0.65	2.42	0.43	0.65	2.29	0.44	0.58
	6 to 7	3.18	0.19	0.52	3.12	0.23	0.51	3.03	0.27	0.54	2.97	0.31	0.48	2.98	0.35	0.49
	8 to 10	4.69	0.08	0.26	4.69	0.10	0.27	4.69	0.11	0.28	4.67	0.12	0.28	4.67	0.15	0.27
¾ to 2 in....	½ to 1	2.11	0.28	0.78	2.05	0.30	0.76	1.99	0.35	0.74	1.91	0.40	0.71	1.88	0.44	0.69
	3 to 4	2.44	0.25	0.72	2.39	0.28	0.74	2.34	0.31	0.73	2.24	0.36	0.70	2.18	0.42	0.68
	6 to 7	3.12	0.18	0.60	3.11	0.23	0.60	3.00	0.22	0.62	2.94	0.26	0.61	2.90	0.30	0.56
	8 to 10	4.69	0.08	0.29	4.68	0.09	0.30	4.67	0.10	0.30	4.61	0.11	0.30	4.54	0.13	0.30
¾ to 3 in.....	½ to 1	1.98	0.25	0.79	1.94	0.29	0.77	1.90	0.34	0.79	1.84	0.35	0.74	1.78	0.40	0.71
	3 to 4	2.33	0.24	0.76	2.28	0.27	0.78	2.21	0.30	0.75	2.12	0.31	0.72	2.06	0.37	0.67
	6 to 7	3.00	0.18	0.62	2.97	0.18	0.62	2.96	0.22	0.66	2.90	0.26	0.64	2.77	0.29	0.62
	8 to 10	4.60	0.08	0.32	4.54	0.08	0.32	4.49	0.09	0.32	4.44	0.10	0.32	4.43	0.12	0.32

229. Special Ingredients and Treatments.—Special treatments (usually calling for proprietary materials) for concrete, and the use of special ingredients, are advocated for one or more of several purposes: To accelerate the setting; to improve work ability; to harden the surface; to decrease water absorption and permeability; or to make possible the use of cheaper materials in the place of sand, gravel or stone. Under normal conditions concrete does not require special treatment or the addition of special ingredients in order to obtain the best possible results. Special processes, above all, cannot make up for insufficient cement, poor aggregates, or poor workmanship.

Calcium chloride at the rate of from 2 to 3 per cent of the weight of cement has for many years been known as an accelerator and a means of protection against freezing, in that it greatly reduces the critical time during which freezing is injurious. Uniform distribution of the chemical may be secured by dissolving the material in the mixing water. The use of hydrated lime is often advocated upon several grounds, the main one being that workability is increased. Information relative to the use of hydrated lime is given in *Bulletin* 8, 1920, Lewis Institute, Chicago, "Effect of Hydrated Lime and other Powdered Admixtures in Concrete." One conclusion given in this bulletin is: "In usual concrete mixtures the addition of each 1 per cent of hydrated lime (in terms of volume of cement) reduced the compressive strength 0.5 per cent. Further information on this subject may be obtained by reference to Bureau of Standards *Technologic Paper* 3, 1911, "Tests of Damp-proofing and Water-proofing Compounds and Materials." *Technologic Paper* 174, 1920, of the Bureau discusses the use of an oxychloride of calcium as an accelerator.

New materials are continually being placed on the market for the purpose of improving results that can be obtained with portland cement alone. Whether or not they are worth anything can easily be shown by making concrete for test, first using cement alone and then in connection with the advertised materials. In the Bates Road Traffic Test carried out by the Illinois Division of Highways the pavement sections included concrete made with a proprietary cement; cement with 2.5 and 4 per cent calcium chloride incorporated; also 7.5 per cent hydrated lime. Illinois *Bulletin* 7, Nov. 10, 1922, states: "The sections containing special cements or other chemicals showed less strength than the plain concrete sections of the same thickness."

CHAPTER XI

MIXERS AND MIXING

230. Mixer Types.—The designs of mixers made by different manufacturers vary greatly, but any of the half dozen or more standard makes advertised in the engineering periodicals are satisfactory. While it is well known that there are three kinds of mixers—batch, continuous and gravity—the batch mixer is used for pavements practically to the exclusion of the others. Batch mixer outfits are divided into two classes, S and E. Mixers of the S class, having side loading and side discharge and no self-traction are usually confined to general construction work, while paving mixers belong to the E class, generally having self-propelled traction with end loading and end discharge. Practically every construction mixer is furnished either on trucks or on skids, there being no difference in the machine itself, but in the equipment furnished with it. Data pertaining to the two classes of mixers, S and E, are given in Table XXIV.

231. Mixer Costs.—The tabulated weights indicate in a general way that some machines are of more rugged construction than others, and accordingly they stand up better under heavy work. To obtain a rough approximation of the cost (1922) of the different sizes from the smallest mixer to the largest, a cost of from 20 to 25 cts. per pound may be assumed to which must be added for delivery \$2 or \$3 per 100 lb., or whatever the freight charge may be. Generally, the smaller machines cost less per pound than the larger and more efficient ones. In choosing a mixer its first cost is not of most importance—operating and maintenance costs must be considered—in fact, requirements for profitable mixer service are, in order of importance (1) endurance; (2) speed of operation; (3) mechanical simplicity; (4) operating simplicity; (5) service in purchase of repair parts; and (6) first cost (see Chap. II, article on “Cost Keeping” for details as to plant charges).

TABLE XXIV.—MIXER DATA

Size of mixer	Horse-power	Class S					Class E	
		Mixer on skids		On trucks with power no traction no charging skip			Paver	
		Weight, pounds	Height, feet	Weight, pounds	Length, feet	Width, feet	Weight, pounds	Width, feet
3	1½ to 2½	500 to 1,000	3 to 4	1,000 to 1,500	5 to 6	4		
4	3 to 4	800 to 1,500	3 to 4	1,500 to 2,000	6 to 8	5		
7	5 to 7	1,500 to 3,000	4 to 5	3,000 to 4,500	8 to 10	6 to 7	7,000 to 8,000	6 to 7
10	8 to 10	2,500 to 4,000	5 to 6	5,000 to 6,000	9 to 11	6 to 7	14,000 to 18,000	7 to 8
14	8 to 14	4,000 to 6,000	6 to 7	7,000 to 9,000	11 to 12	6 to 7	18,000 to 22,000	8 to 9
21	12 to 18	6,000 to 8,000	7 to 8	9,000 to 12,000	12 to 13	6 to 7	20,000 to 26,000	9 to 10
28	18 to 25	7,000 to 9,000	8 to 10	12,000 to 14,000	13 to 15	7 to 8	30,000 to 35,000	10 to 11
56	35 to 45	14,000 to 16,000	9 to 12					
112	80 to 100	40,000 to 55,000	15 to 20					

NOTE.—Horsepower figures apply to electric or steam. A gasoline engine should be provided with a large excess of power in order to allow for dirty spark plugs, too much oil, worn pistons, etc.

232. Class S Mixers.—Class S mixers on skids are illustrated in Figs. 103 and 104. Practically all manufacturers turn out Class S mixers for skid mounting. They are on the market from the smallest size, No. 3-S, to the largest, No. 112-S. Power and secondary equipment and attachments for use with the mixer can be obtained with it, but often mixers on skids are bought alone and fitted into existing plants, whether the power be gasoline, steam or electric.

Mixers on trucks are illustrated in Figs. 105 and 106. Generally, manufacturers mount all styles of their mixers on trucks, except in the very largest sizes. The type shown in Fig. 103,

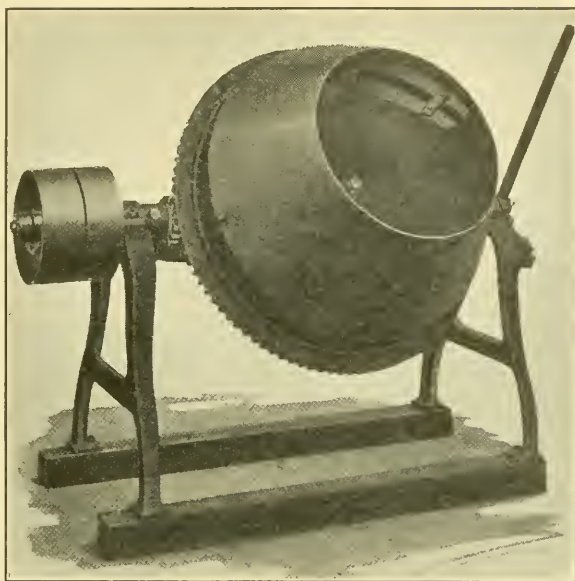


FIG. 103.—An economical type of mixer for small work, usually limited to No. 7 size or smaller. Can also be obtained mounted on trucks and with loading skip.

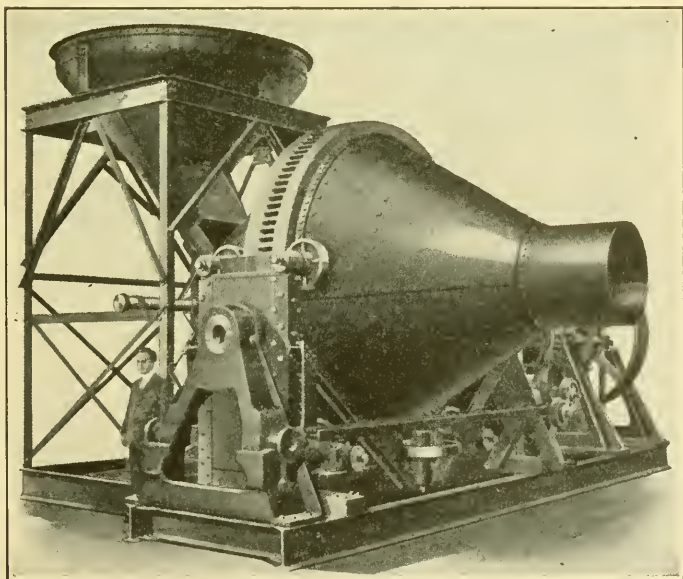


FIG. 104.—A heavy type of machine, obtainable up to and including the No. 112 S. size.

when mounted on trucks is popular for small work. It may be noticed that the batch is both fed into and discharged from the one drum opening. Small mixers such as this are generally operated by gasoline motors, and though of comparatively light weight they are well worth their cost. For heavier types of mixers there are two methods of discharging. Some receive the charge into the drum at one end and the drum is tilted in order to discharge from the other end, an example being the mixer illustrated in Fig. 104. Other mixers have drums that do not

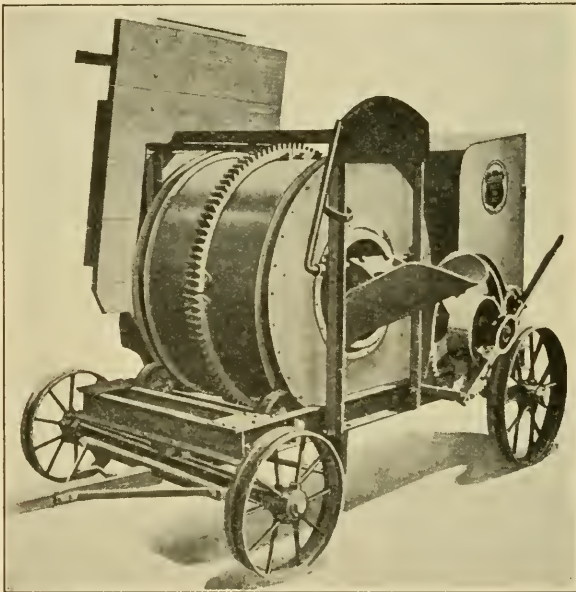


FIG. 105.—A type of mixer and truck often seen on general construction work. Charging is done from a timber platform by the direct use of barrows.

tilt, but discharging is accomplished as illustrated in Fig. 105, by means of a discharge chute, which is thrown into or out of the drum opening.

It is not uncommon to find the mistake being made of using a Class S mixer where a Class E should be used. For some work, as for instance in a narrow alley, the side discharge truck mixer is very unhandy, and in such cases it is found that barrow men, at much expense, wheel aggregate long distances to the mixer and concrete long distances from it. Some small mixers, especially of that type shown in Fig. 103, are mounted so that they can be

rotated on the trucks and discharge either to the side or to the end, thus combining in one machine both Class S and Class E principles.

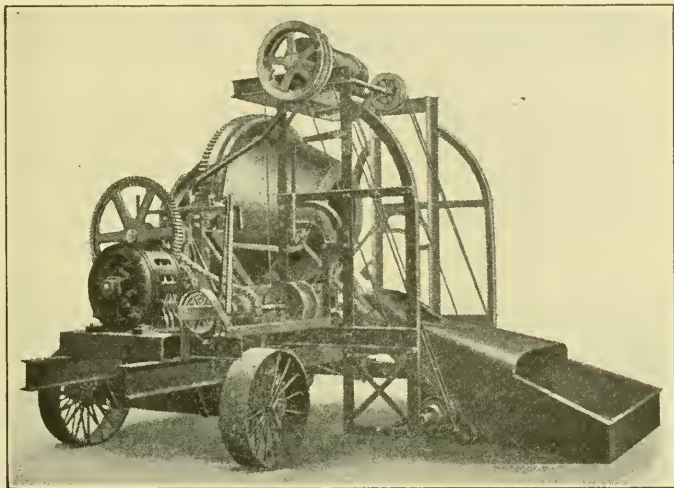


FIG. 106.—A heavy duty type of mixer.

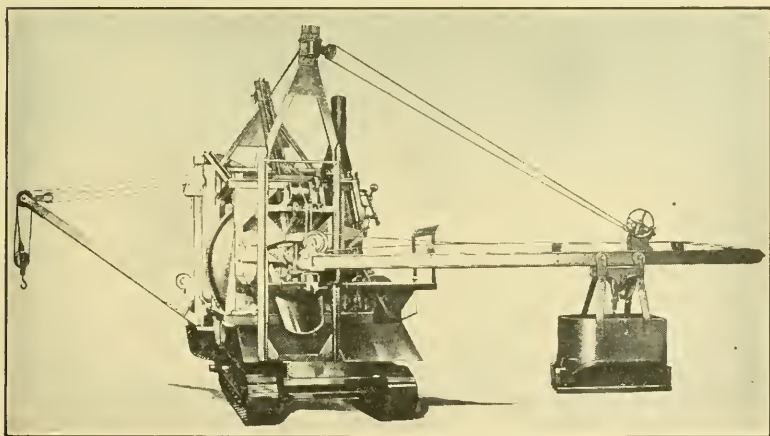


FIG. 107.—The complete paver. Usually made in sizes Nos. 7 to 28 inclusive. The derrick attachment picks up batch boxes and dumps them into the loading skip of the mixer.

233. Class E Mixers.—Class E mixers are designed primarily for paving work. An example is illustrated in Fig. 107. Some manufacturers are confining their pavers to three sizes, Nos. 10-E,

14-E, and 21-E. Others make also, sizes 7-E and 28-E. No. 21-E is the largest that is economical for ordinary work. It mixes concrete about as fast as the best of organizations can deliver materials and handle the concrete as discharged. The No. 28 size is suitable only for extraordinary paving projects; for example, such as have been contracted for recently by one or two states.

234. Power.—For portable types of mixers generally either gas engines or steam are used. Electric motors are often used for stationary mixers. Gas engines are invariably of higher rated horsepower for each size of mixer than either steam or electric. Several years ago steam was greatly favored for large pavers.

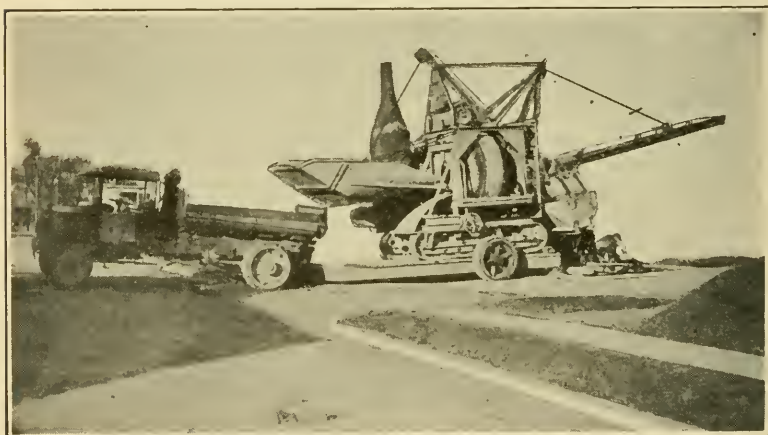


FIG. 108.—A 21-E paver loaded on a low trailer for transportation from job to job about a city.

Lately high grade, reliable, and economical gasoline units have been perfected for pavers and are now a popular choice. Steam is objectionable in cases where conditions relative to the employment of steam engineers and firemen are so unreasonable as to make operation costs excessive. If a gas engine is used for a large mixer it should be of four cylinders and have plenty of excess power. The choice of a gas engine, of course, does away with the trouble of handling heavy fuel, getting up steam, firing the boilers, cleaning boilers, etc.

235. Traction.—Multiple tread traction as illustrated in Fig. 107, handles better on the job and does not sink into soft ground as readily as do wheels, though the latter give swifter movement

from job to job, which is an important element in city work because generally a season's work is made up of a large number of small items widely distributed throughout the city. Even with wheels, however, paver speeds generally are less than $1\frac{1}{2}$ miles per hour. If hauled as a trailer behind a truck at greater speeds, the machine is unduly shaken and jolted. This can be corrected by mounting the mixer on a truck equipped with rubber tires and motor vehicle bearings. If a trailer is made with motor-truck wheels and bearings and a chassis close to the ground, so that a multiple tread paver can crawl aboard by its own power and be hauled as illustrated in Fig. 108, then much time can be saved, wear and tear greatly reduced and multiple tread traction used to the best possible advantage.

236. Boom and Bucket.—Now that the use of relatively dry concrete is firmly established, boom and bucket distribution is becoming more commonly used, though a chute is cheaper in first cost, and cheaper in maintenance. Depending upon the size of the machines, booms range from 15 to 20 ft. in length. With some mixers certain faults have been noticed. A purchaser should be sure that the boom can be swung when out of horizontal when working up or down hill, that the bucket is full-batch capacity, and that it can be handled for the full length of the boom without over-balancing the machine. Deficiencies as to these points probably have been corrected in all recent mixer models.

237. Mixing.—When the operations of making concrete in the field can be automatically controlled so that they will not be subject to the personal equation of the laborer on the job nor to the desire on the part of those in charge to increase profits at the expense of the concrete, then only can the maximum practicable efficiency be obtained, and the product made to approach a standardized concrete. The measuring of aggregates and other matters dealing with proportioning were treated in Chap. X. The following 1921 tentative specifications of the Joint Committee deal directly with mixing.

238. Machine Mixing.—Mixing, unless otherwise authorized by the engineer, shall be done in a batch mixer of approved type which will insure a uniform distribution of the materials throughout the mass, so that the mixture is uniform in color and homogeneous. The mixer shall be equipped with suitable charging hopper, water storage, and a water-measuring device controlled from a case which can be kept locked

and so constructed that the water can be discharged only while the mixer is being charged. It shall also be equipped with an attachment for automatically locking the discharge lever until the batch has been mixed the required time after all materials are in the mixer. The entire contents of the drum shall be discharged before recharging. The mixer shall be cleaned at frequent intervals while in use.

239. Hand Mixing.—When hand mixing is authorized by the engineer it shall be done on a watertight platform. The materials shall be turned at least six times after the water is added and until the batch is homogenous in appearance and color.

240. Retempering.—The rettempering of concrete or mortar which has practically hardened, that is, remixing, with or without additional cement, aggregate or water, shall not be permitted.

241. Water.—The importance of maintaining the proper consistency being apparent, the necessity of having a measuring gauge regulating the amount of water for each batch, is readily realized. The necessity of taking care of such variable factors as rain-soaked or sun-dried aggregates must, however, be recognized and the water lock required by the Joint Committee's specifications should not be made such a permanent fixture as to make it difficult to compensate for these variables.

In addition to the provisions as to measuring water the Joint Committee proposed:

"Water.—Water for concrete shall be clean and free from oil, acid, alkali, organic matter, or other deleterious substance."

242. Time of Mixing.—The time of mixing is an important element and as it largely controls the output of the mixer, and therefore the cost of the concrete, it needs careful consideration. Tests with various batch mixers at present on the market show a rapid increase in strength for the first minute concrete is mixed, and a smaller increase for the second minute, after which the increase continues smaller as the time of mixing increases. The increase in strength appears whether the concrete is tested at 7 days or after the lapse of considerable time. While some engineers now specify a $1\frac{1}{2}$ -min. mix, the great majority of contractors appear to believe that the excess cost thereby entailed over that for a 1-min. mix is not justified by the extra strength obtained. The addition of a little cement for extra strength should be given consideration in place of lengthening the time of mixing.

It may be that in the near future an improved mixer will be developed that will give full strength concrete in less than 1 min.

Such a machine would add much to the economy of mixing. There is now no question, however, as to fixing 1 min. as a minimum. If less time is specified, water is not worked through the mass as it should be, and in order to get his consistency, the mixer man may use more water than should be permitted. A batch meter to insure the full mixing time after all the ingredients, including the water, are in the drum is absolutely necessary. The Joint Committee proposed:

Time of Mixing.—The mixing of each batch shall continue not less than $1\frac{1}{2}$ min. after all the materials are in the mixer, during which time the mixer shall rotate at a peripheral speed of about 200 ft. per minute. The volume of the mixed material per batch shall not exceed the manufacturer's rated capacity of the mixer.

243. Speed of Drum.—The Joint Committee recommended a peripheral speed of about 200 ft. per minute. This means that a drum of large diameter would be permitted to revolve slower than one of smaller diameter. Generally the drum speed has been specified in the past in terms of revolutions per minute. With practically all makes of batch mixers there is little effect on the strength of concrete within the limits of 10 to 30 r.p.m. If the drum is not over-loaded, mixers as furnished by the manufacturers will give satisfactory drum speed—the main thing is to see that the charge is mixed for at least 1 min.

244. Mixer Ratings.—According to the Concrete Mixer Association the quantity of mixed concrete a mixer can deliver is used as a rating basis, and mixer numbers indicate the capacities in cubic feet of mixed concrete per batch. The amount of concrete obtained from a given quantity of unmixed material depends greatly upon the character of the aggregate, also upon the amount of water used. Data prepared as explained under "Estimating," Chap. X, give a precise method of calculating a loose unmixed batch in terms of mixed concrete; however as a rough rule-of-thumb, the capacity in unmixed material per batch, for each size of mixer, in cubic feet, may be assumed to be $1\frac{10}{7}$ times the mixer number (in place of $1\frac{10}{7}$ the ratio 3:2 is often assumed). Usually it is considered for rating purposes that mixers are able to turn out 40 batches per hour. Accordingly, since the ratio 10:7 is approximately the same as

$$\frac{40 \text{ batches per hour.}}{27 \text{ cu. ft. in 1 cu yd.}}$$

the figures representing the batch capacities in cubic feet of unmixed material may also be taken as representing the rated output per hour of mixed concrete in cubic yards. It must be realized that "rated output" is an arbitrary figure chosen for classification purposes. It too often differs greatly from "actual output" which latter figure depends upon the time of mixing and upon the equipment available for getting materials into the mixer and concrete away; and further upon the organizing ability of the man in charge and his efficiency in handling his equipment.

Mixer ratings are shown in Table XXV, also bag capacities per batch for four commonly used concrete proportions.

TABLE XXV.—ARBITRARY RATING TABLE FOR MIXERS

Size of mixer	Capacity, mixed concrete per batch	Capacity, unmixed material	Rated output at 40 batches per hour	Cement per batch			
				1:3:6	1:2½:5	1:2:4	1:2:3
Number	Cubic feet	Cubic feet	Cubic yards	Bags	Bags	Bags	Bags
3	3	4.3	4.3	0.43	0.50	0.61	0.72
4	4	5.7	5.7	0.57	0.67	0.81	0.95
7	7	10.0	10.0	1.00	1.18	1.43	1.67
10	10	14.4	14.4	1.44	1.68	2.05	2.40
14	14	20.0	20.0	2.00	2.35	2.85	3.35
21	21	30.0	30.0	3.00	3.55	4.30	5.00
28	28	40.0	40.0	4.00	4.70	5.70	6.65
56	56	80.0	80.0	8.00	9.40	11.40	13.30
112	112	160.0	160.0	16.00	18.80	22.85	26.65

It is seen from the table that the factor 7 enters largely into the numbering of mixer sizes, and that for a 1:3:6 mixture, the sum of the ingredients being 10, the cement per batch for a No. 7 mixer equals 1 bag, for a No. 14 it equals 2 bags and so on, to 16 bags for a No. 112. This appears to explain to some extent the choice of the ratio 7:10 as a factor for changing from unmixed materials to mixed concrete.

The fractional figures in the last four columns of the table do not signify that a contractor would split a bag of cement; in fact most specifications prohibit such a procedure, though if the

cement is in bulk, exact quantities might be used in order to obtain full mixer capacity. The data in these four columns show that the scheme often followed of basing mixer capacities on rich concrete and calling the No. 10 mixer a two-bag machine, the No. 14, a three-bag machine and so on, is much too general a characterization. Also these data show whether or not there is a tendency to over-load the mixer when a full bag mix is used as an approximation to the capacity of the mixer. Most manufacturers' ratings are conservative and allow for approximately 10 per cent excess capacity on all sizes, though there is some difference in mixers rated of equal size, but made by different manufacturers. If a mixer labors under its charge, turns over slowly and gives poorly mixed concrete, it is undoubtedly overloaded. One objectionable feature connected with mixer overloading is that a tendency is created to use an excessive amount of water in order to give the poorly mixed concrete the desired consistency.

245. Actual Output of Mixers.—Both engineers and contractors seldom realize how little time is consumed on actual work under contract, and how much avoidable delays increase the cost of construction operations. This is particularly true in the case of concrete paving. There are the usual delays which may be charged to "Administration," including for example, time consumed in contractual formalities, shipping equipment, organizing forces, and other preliminary work carried out after the award of the contract, but before work is actually commenced. Bad weather is always the cause of many days lost time; the only lost time, though, which is fully excusable. Moving from job to job consumes much time. Lack of materials frequently causes considerable delay which can generally be avoided by using foresight in laying out proper storage. Lack of water supply is a frequent cause of delay, often simply because water pipe too small in diameter has been purchased. Although in cities the source of supply is generally ample, sometimes pumps have to be installed, in which case care should be taken to have them large enough. A delay that is always avoidable is that where failure to prepare the sub-grade in time prevents continuous operation of the mixer. Waiting for the completion of accessory and incidental work, curb setting, the installing of gas, water and other services, etc., invariably uses up a great deal of time and this can be remedied only through the closest possible coordination.

In Illinois during 1921, of 102 contractors' paving mixers, one operated 129 days; two 121 days, two 105 days, and all the rest less than 100 days. In Iowa, during the same year, mixers used on 31 different contracts spread throughout the state, averaged but 74 operating days and only 55 full days were worked, calling every day a full day if the lost time was less than $\frac{3}{4}$ hr. Of 35 per cent lost time, only 1.09 per cent was lost because of machinery breakdowns.

A knowledge of the season's probable output of a mixer is important, not only that a unit charge may be made for interest on the cost of plant and for depreciation, but also in order that a large enough mixer may be bought to complete all the work laid out for the season. The time that the charge has to remain in the mixer being fixed at a minimum of 1 min., which is practically twice as long as was common practice a few years ago, every effort has been made of late to speed up the other operations connected with mixing. With a fast operating mixer a total allowance of 20 sec. is sufficient for charging and discharging and, if the crew is well organized and the operators skilled, there should be but little incidental lost time. Thus the minimum time consumed per batch is definitely fixed. The larger part of this time is taken up in mixing the charge, and output can be increased only by reducing the number of batches, which plainly shows the necessity of choosing the largest mixer that can be successfully handled on the job.

CHAPTER XII

METHODS OF MIXING AND DELIVERING

246. The Three Common Methods.—There are three methods of mixing and delivery generally employed for concrete roadway construction: Roadside proportioning, central proportioning, and central mixing. The essential difference is in the hauling. In the first method, the aggregates and cement are hauled separately, stocked near the mixer at the job, and there combined. In the second, the ingredients are put together in correct proportions at a central plant and dry batches are hauled to the mixer. In the third, the wet batches are hauled from a central mixer to one or more distant jobs.

No one of these methods is suitable for all conditions. That one should be adopted which, after an analysis, shows the least cost per yard of concrete. A large expenditure for plant is not justified unless a large volume of work is done and the plant charges per unit of work are thus minimized.

247. Roadside Proportioning.—In many cases, pavements can be built cheaper by using wheelbarrows and charging the mixer from stock piles on the sub-grade, than by other methods requiring expensive equipment. For the delivery of materials special truck bodies are not required, just general utility dump trucks, and hauling does not have to be so closely coordinated with mixer operations as when either wet or dry batches are hauled. In cities contractors mixing from the sub-grade often have their hauling done by others who carry on a general trucking business. This saves the pavement contractor the large outlay that would otherwise be necessary if he had to have trucks of his own.

Storage on the sub-grade of course wastes aggregate—from 5 to 10 per cent—and adds to the work that has to be done to maintain the sub-grade at the correct contour; but these are expenses that must be balanced against outlays for other equipment that would make unnecessary such storage. When motor trucks are used for hauling, care must be exercised that the sub-

grade is not too much cut up and rutted. After the aggregates are on the ground and mixing has started it is generally impracticable to use a roller effectively. The distribution of materials along the line of work must be nicely balanced; otherwise, it will be found that much labor will be expended in wheeling excessive distances from the piles to the mixer. In any case, barrow charging of the mixer requires a great deal of labor; often for each barrow, one man to wheel and one to load. Since a barrow holds about 2 cu. ft., this means that with a four-bag mixer there may be 20 men needed for handling sand and coarse aggregate.

Taking out time for raising and lowering the charging skip there is left, if good operating time is to be made, only 30 sec. or less for the wheelers to empty their loads into the skip. This means that for large mixers the skip should be wide enough to permit emptying two barrows simultaneously. On a few large jobs success in the replacement of men by machinery has been achieved by the use of belt conveyor loaders. For the inspector on the job, one last word of instruction is necessary: "Make sure that earth from the sub-grade is not mixed with the aggregates and dumped into the mixer."

For the large number of small jobs that have to be done about a city, unfavorable factors connected with roadside proportioning are apt to be magnified. Separate sidewalk and alley items are seldom or never above 1,000 sq. yd. in extent, and many of them are even less than 100 sq. yd. In repair work the separate patches are very small. In the District of Columbia making 15,000 concrete repairs per year it was found that the patches averaged but $2\frac{1}{2}$ sq. yd. each. Under these conditions mixers have to be moved from place to place every few days and in addition, wheelbarrows, horse-drawn carts or small trucks have to be used for delivering concrete to all those small jobs which may be considered within an economical radius of each set up. Delivery of concrete under these conditions is very expensive.

248. Central Proportioning.—The usual equipment of a central proportioning plant consists of an unloading derrick, over-head bins and a cement warehouse. The proportioned batches are hauled to the job either in trucks with special bodies or else carried in batch boxes. In the first case the batch is dumped from the truck directly into the mixer skip, as illustrated in Fig. 109. In the latter case a mixer mounted crane lifts the boxes, dumps the batches into the skip and returns the boxes to the

transporting vehicle. The delivery of materials has to be timed accurately with operations of the mixer or else much time will be lost.

By central proportioning, large economy in handling materials is possible. Aggregates are moved from the rail or water terminal directly into the mixer, and in addition it is practicable to use bulk cement which some contractors estimate means a saving of about 15 cts. a barrel. On the other hand, the large outlay necessary for expensive hauling equipment needs serious con-

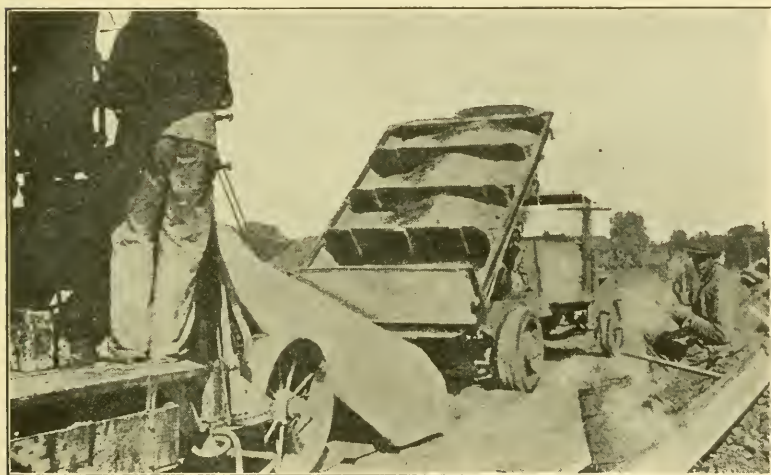


FIG. 109.—Charging mixer with proportioned batches hauled in trucks.
(Courtesy U. S. Dept. of Agriculture)

sideration especially in view of the fact that any tie-up in the transportation throws the entire mixer and paving force into costly idleness.

249. Central Mixing.—Central mixing presents many problems similar to those of central proportioning. It requires close coordination of transportation, and extreme carefulness as to the quality of the concrete. Segregation (separation of the aggregate from the other components) is one of the most troublesome factors in transporting wet concrete. When an attempt is made to remedy this by furnishing a drier mixture the concrete is often not workable and cannot be brought properly to a finished surface. Another point to be considered is that the weight of the water in the mixed concrete adds to the cost of hauling compared with the cost of dry-batch haulage.

Concrete has been hauled successfully 6 and 7 miles. Some engineers set the economic limit at a 1-hr. haul. Whether or not any particular mixture can be satisfactorily hauled cannot be determined by the slump test. Only by actually trying out several batches can a safe and practicable determination be made as to the degree of segregation that will take place en route and whether or not the concrete will be workable upon arrival at its destination.

Much can still be learned about constructing pavements by the central mixing method and it is not surprising that some of those who have tried this method have failed. Undoubtedly large



FIG. 110.—A mixture dry enough to dump easily from trucks with 45-degree hoists needs careful investigation even for concrete base construction.

economies are possible; in the handling of the aggregates, by the use of bulk cement, and in the preservation of the sub-grade contour. A central mixer should be particularly adapted to city work where the concreting to be done comprises a great many small repair jobs as well as a number of small street and alley paving items, all of which, while scattered, may be grouped about a central point within satisfactory hauling distance.

In the District of Columbia approximately 15,000 cu. yd. of concrete, the equivalent of 90,000 sq. yd. of 6-in. pavement, are used yearly on small work of the nature just described, and because of the difficulty of handling such work by contract it is done by city employees and plant. The high cost of doing this work by roadside proportioning methods well justified extensive investigation of central mixing. In addition such an investiga-

tion was called for in order to decide whether or not contractors would be permitted to use trucks with 45-deg. hoists, as illustrated in Fig. 110, for the construction of concrete base by the central mixing method.

It may be noticed that the concrete in the trucks shown in Fig. 110, did not flatten out, but remained heaped in the bodies after having travelled several miles. Since a base does not have to be given the smooth wearing surface finish of a one course pavement, the concrete may be relatively dry, but it should not be so dry as to give a mealy mixture that cannot be properly compacted. When this is the case more water must be used, though the contractor is compelled thereby to substitute other body equipment on his trucks, or even give up entirely the central mixing method.

Using concrete no wetter than would dump from trucks with 45-deg. hoists (no slump by the cone test), three mixtures were investigated, 1:2:5, 1:3:6, and 1:3:7, using Potomac River $\frac{1}{4}$ -in. sand and $1\frac{1}{2}$ -in. gravel. To determine what improvement would result if more water were used in the concrete, boxes 4 ft. square and 6 in. deep were filled with the mixtures as dumped from the trucks and then tamped in the same manner as habitually used on the roadways.

These definite amounts of concrete were then mixed with additional water so as to give a cone-test slump of from $\frac{1}{2}$ to 1 in., and then the concrete again tamped in the boxes, expending no more labor than in the first instance. It was found that though from $\frac{1}{3}$ to $\frac{1}{2}$ gal. of water per cubic foot of concrete had been added the boxes lacked being full by $\frac{1}{2}$ in. This means that the use of dry mealy mixtures that cannot be easily compacted hold out for the contractor approximately 8 per cent of the materials that should be in the pavement. Moreover such concrete is not nearly so strong as if it were properly compacted. For instance, 1 cu. ft. of this dry concrete should really be compacted to 0.92 cu. ft., since the excessive voids amount to 8 per cent. For a 1:2:5 mixture, 0.92 cu. ft. of concrete of such compaction as can easily be obtained with a consistency represented by a slump of from $\frac{1}{2}$ to 1 in., contains 15.3 lb. cement, occupying 0.218 cu. ft. of space; that is, 70 lb. cement per cubic foot of space occupied; corresponding to a compressive strength of 2,000 lb. per square inch. If the space is increased by 0.08 cu. ft. we have 15.3 lb. cement, occupying 0.298 cu. ft. of space; that is,

0.515 lb. cement per cubic foot of space occupied; corresponding to a compressive strength of 1,075 lb. per square inch. Thus the deficient compaction obtained because the 1:2:5 concrete is not sufficiently plastic results not only in a 92-per cent pavement as far as quantity of concrete is concerned, but the concrete has but 54 per cent of its proper strength.

As a check on the conclusions of this investigation, a number of 6 by 12-in. cylinders were made with the dry concrete mentioned in the preceding paragraph. The mixture was poorly tamped in half the cylinders and well puddled in the remainder. The poorly tamped ones weighed but 88 per cent as much as the



FIG. 111.—A mix satisfactory for one course work compacts in the truck body and a 45-degree hoist is not sufficient to dump the load.

puddled cylinders and showed by the compression test but 40 per cent of the strength of the latter.

One point which makes handling concrete from a central plant more difficult for city work than for country roads, is the fact that machines cannot be used for bringing the concrete to a proper surface. On repair work, hand methods have to be used; also on alleys and streets, due to their unsymmetrical sections and frequent intersections it is impractical to use machines for finishing. Concrete for hand methods has to be more plastic than for machine finishing.

For base construction, satisfactory work can be accomplished with Potomac River aggregates, using lean mixtures if the slump

by the cone test lies between $\frac{1}{2}$ and 1 in. For one course work with rich mixtures, the slump should lie between 1 and $1\frac{1}{2}$ in. In order to determine whether a central plant could meet these conditions, various mixtures, from very lean ones to very rich ones, were tried. Many different types of truck bodies were used and time consumed on the road delivering the wet batch was varied up to a limit of 1 hr. It was definitely determined that trucks with ordinary hoist bodies as illustrated in Fig. 111, are unsatisfactory on account of the excessive picking and shoveling required to move the concrete. The practices of sprinkling sand in the bottoms of the trucks, sprinkling with lime, or painting the inside of the bodies with oil, in the hope of making the

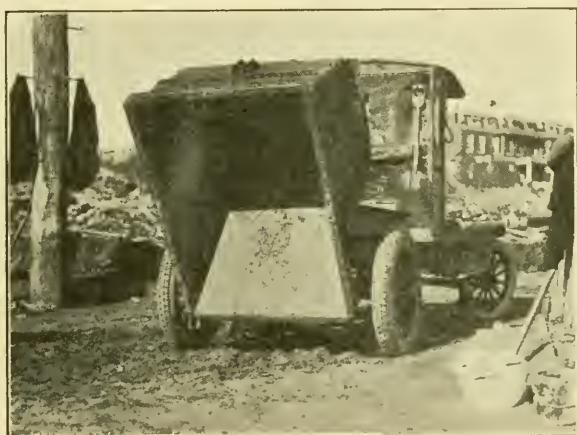


FIG. 112.—Gravity dump body. This type turns over to such a degree that the load is instantly released.

loads slide are not to be recommended. Gravity dump bodies as illustrated in Figs. 112 and 113, gave good results and the investigation showed that concrete can be delivered by them in condition satisfactory not only for base and one course roadway construction, but also for one course sidewalk.

Compression tests showed that concrete after a 1-hr. haul was equal in strength to that produced by roadside mixers. Consistency was measured by the cone test at the mixer upon loading the trucks and again on the job as the loads were dumped, and a considerable decrease in "slump" was found. On work of this nature care has to be exercised when a load is dumped,

in order to be sure that representative specimens are obtained for the compression and cone tests. While segregation that may take place en route may not be sufficient to interfere with good pavement construction, it may be enough to give erratic test results unless care is taken to obtain average samples.

In order to deliver concrete of a definite consistency, it must contain excess water when sent out from the plant; the excess is to compensate for drying out en route, and its amount depends upon the nature of the aggregates and their proportions, upon climatic conditions and upon the length of haul. There is, however, a limit to the excess water that may be used because



FIG. 113.—Dual hopper gravity dumps.

beyond a certain amount it will be found that shortly after the truck leaves the plant segregation of the water takes place, and the greater the amount of excess water the quicker it comes to the top and the drier the concrete underneath appears to be. Upon dumping the load this water, carrying some cement with it, flows off the top of the concrete and is wasted into the subgrade. The concrete underneath cakes in the truck so that it is with difficulty taken out and then gives an unsatisfactory surface finish.

Using Potomac River aggregates with mixtures richer than 1:2:4, it was found that a slump of $3\frac{1}{2}$ in. could be used as marking the limit of excess water beyond which it was not well to pass. Slumps of from $2\frac{1}{2}$ to 3 in. gave good results after a

1-hr. haul. With these slumps there would be some segregation, that is, a film of mortar would show on top of the concrete, but water as distinct from mortar would not be present. Mixtures leaner than 1:2:4 could not be controlled as nicely as richer ones. With the latter, as the amount of water was increased, slumps could be obtained from zero to 6 in., varying uniformly by small increments. With lean mixtures after a slump of about 2 in. was obtained, the addition of water caused the cone to slump quickly as much as 6 in., and the leaner the mixture the more difficult it was to measure slumps between 2 and 6 in. Thus it was found that with a lean mix and a slump of more than 2 in., water very readily came to the surface en route. However, since surface finish is not so important for base construction, it was found practicable to use mixtures not so wet as to give poor

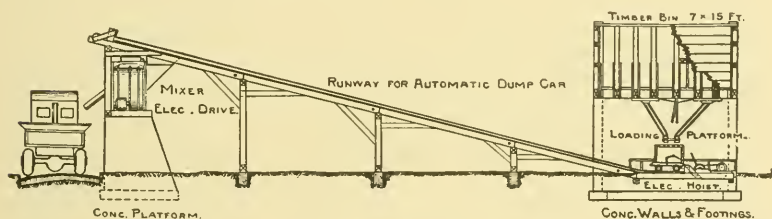


FIG. 114.—A central mixing plant using a three-bag mixer and having a bin storage for one hour's operation.

results in hauling and yet not so dry as to give poor results in constructing the pavement. The conclusion may be drawn that the central mixing method can be used successfully for general highway work about a city. There are, however, many details that have to be worked out locally and carefully controlled by the engineer.

250. A Central Mixing Project.—To illustrate the drawing up of a project for a central plant, the following example is given, based on an average hauling distance of $4\frac{1}{2}$ miles from the mixer to various small jobs distributed about the District of Columbia: The site for the plant is assumed at the water front, with electric power for operation, over-head storage and measuring boxes for aggregates, and direct discharge from the mixer into motor trucks. A No. 14-S mixer is chosen, and the plant layout is as shown in Fig. 114, the cost being as listed in the accompanying table.

TABLE XXVI.—ESTIMATE OF COST FOR CENTRAL MIXING PLANT

Bin			
4,481.0 b. ft. lumber.....	@ \$130.00	\$ 582.53	
17.7 cu. yd. concrete.....	@ 30.00	531.00	
315.0 lb. reinforcing steel.....	@ 0.06	18.90	
248.8 lb. structural steel.....	@ 0.10	24.88	
474.2 lb. bolts.....	@ 0.30	142.26	
		<u>\$1,299.57</u>	1,299.57
Trestle			
1,691.3 b. ft. lumber.....	@ \$130.00	\$ 219.87	
1.0 cu. yd. concrete.....	@ 30.00	30.00	
		<u>\$ 249.87</u>	249.87
Mixer Platform			
6.5 cu. yd. concrete.....	@ \$ 30.00	\$ 195.00	
174.0 lb. reinforcing steel.....	@ 0.06	10.24	
		<u>\$ 205.24</u>	205.24
1 Mixer (No. 14).....		\$1,750.00	
1 10 hp. No. 173 A.C. hoist.....		810.00	
70-ft. portable track, 2-ft. gauge.....		49.00	
28-in. pulley wheels with parts, etc.....		34.66	
150 lin. ft. $\frac{5}{8}$ -in. cable.....	@ 12 cts.	18.00	
1 Dump car.....	@ \$85	85.00	
2 Chutes.....	@ \$30	60.00	
		<u>\$2,806.66</u>	2,806.66
Plus 15 per cent (overhead and contingencies).....			688.66
			<u>\$5,250.00</u>

For a modern No. 14-S mixer, an estimated output of 120 cu. yd. per day is conservative, and would take but 125 operating days per year to give a required total of 15,000 cu. yd., or 90,000 sq. yd. 6 in. thick. Since there should be little or no lost time on account of "administration," moving from job to job, and lack of materials, a plant such as this should be able to work 200 days per year and, therefore, the estimate of 125 days allows a large leeway for contingencies and also for future expansion of the output.

A three-bag batch of 1:1 $\frac{5}{8}$:4 proportions may be assumed to give 13 cu. ft. of mixed concrete, weighing as follows:

	POUNDS
3 bags cement.....	282
4 $\frac{7}{8}$ cu. ft. sand.....	487
12 cu. ft. gravel.....	1,200
19 gal. water.....	<u>160</u>
Batch weight.....	2,129

Having determined upon the No. 14 mixer as the largest size warranted by the volume of work to be done, the next question is as to the number of batches to be carried per truck. With an average haul of $4\frac{1}{2}$ miles, about one truck trip per hour would be made, and the actual time loading at the mixer would be but a small portion of the truck trip time. If 10 trucks are required when carrying three-batch loads, then practically 30 would be required if only one-batch load were carried.

It is thus apparent that as many batches should be carried per truck as it is estimated can be readily handled by the men on the street. For alley, sidewalk and patching work it is considered that a three-batch load is best; and this load would also do for patching, by using dual hopper bodies, so that half the load could be dumped at one locality and the remaining half at another. The purchase of no more than ten 3-ton trucks, five with single bodies and five with dual hoppers, would be warranted. On days when more would be needed the fleet would be supplemented by hired trucks. In order to employ the truck drivers full time, keeping the trucks busy a maximum number of days in excess of the 125 required for concrete hauling, they would be used at odd times for hauling stone and other paving materials; thereby displacing a number of trucks that are at present hired.

251. Transportation by Truck.—There have been a great number of failures among those using trucks for hauling and most of them have been due to neglecting to allow for depreciation and proper maintenance. Many operators have seemingly made money until suddenly they discovered their equipment worn out and no money set aside for replacements. Experience has shown that trucks especially equipped for the work, as well as other paving equipment, often do not make a fair number of working days per year. It is often advantageous to have hauling done by contract, thereby saving a large outlay for equipment and at the same time getting the work done more economically, since a hauling contractor, because of the general nature of his business can find work for his trucks daily throughout the year.

The analysis of operating costs may best be illustrated by means of an example. Assume that a 5-ton truck averages 55 miles per day, works 250 days per year (this is a high average but is attained by many hauling contractors under city conditions), and carries full loads in one direction only, returning empty; then costs may be tabulated as follows:

TABLE XXVII

Driver's wages.....	\$1,200.00
Depreciation (20 per cent on \$5,000).....	1,000.00
Interest (6 per cent on \$5,000).....	300.00
Insurance.....	300.00
Garage.....	150.00
Maintenance, minor repairs and supplies.....	400.00
Complete over-haul, once a year.....	400.00
License fees.....	100.00
Tires.....	360.00
Lubricants.....	90.00
Gasoline.....	1,200.00
Total per 250 operating days.....	\$5,500.00
Per operating day (250 per year).....	\$ 22.00
Per operating mile (55 per day).....	0.40
Per delivery mile (27½ per day).....	0.80
Per ton, delivered 1 mile (5 tons per trip).....	0.16

From an inspection of the table it is clear that ton-mile costs may be reduced in three primary ways; increasing the number of operating days per year, increasing the daily mileage, and carrying loads on the return trips. Many truck owners try to reduce costs by carrying 7 or 8 tons on a 5-ton truck, but in the long run this does not pay. If there is a regular field for such heavy hauling 7½-ton trucks should be purchased.

252. Industrial Rail and Cars.—As it is necessary to keep cross streets open for traffic, industrial rail and cars find a very limited field of use in city paving work. They have been used to some small extent in order to deliver concrete from a mixer located on a side street contiguous to the one under construction. All mixing operations are thereby concentrated at one fixed spot, and aggregates are not handled on the sub-grade. In reality this method gives a central mixing plant close to the job, with short haul delivery over the sub-grade. Another adaptation of track and cars is the hauling of batch boxes for short distances to a mixer which deposits the concrete directly in place. In either case, trucks bring the materials over the city streets from the yards to the vicinity of the job, and the track and cars obviate hauling over the sub-grade which once prepared may thus be kept in good shape.

Track generally used is portable, consisting of short sections of light rail fastened to steel channel ties. Most contractors have adopted a 2-ft. gauge. Cars are usually pushed singly by man

power. The V-dump type with side height of about $3\frac{1}{2}$ ft. is most popular for delivering a wet batch. They should be no larger than $\frac{3}{4}$ -yd. capacity, which one man can push at a speed of about 200 ft. per minute and average throughout the day, including loading and waiting time, about 100 ft. per minute. From these data costs of delivery may be computed. Generally, it will be found that 500 ft. more or less, dependent upon the wages of labor, is the maximum economical distance. For greater distances a small locomotive might be used running the cars in trains but such plant is warranted only on work of large volume and finds little or no application in cities where, as has been stated before, cross streets have to be kept open. With either locomotives or man power, difficulty is had if track is laid on grades of much more than 3 per cent.

CHAPTER XIII

CONCRETE CONSTRUCTION

253. Specifications.—It is well to emphasize some points that were brought out in Chap. III, "Work by Contract." As to the details of construction, specifications of no two cities are alike. While it is realized that details depend upon local conditions, it is hoped that nevertheless, during the next few years progress will be made in standardizing and simplifying construction specifications. Work to be done should be described in plain words and it is unnecessary to make use of such uncertain terms as "to the satisfaction of the engineer" "of approved type" and "as may be directed."

254. Sub-grade.—Lines and grades are established by the engineer and no work should be commenced until these are given. Every reasonable aid should be extended to public utility interests in their installation of both surface and sub-surface structures. Railway tracks, curb, manhole and valve-box frames, etc. should be checked and released by the engineer. The area over which the pavement is to be laid, after being graded to the proper depth, should be compacted by rolling and by hand ramming at places that cannot be reached by the roller. For sidewalks the sub-grade is usually tamped entirely by hand. When the soil is so dry that it cannot be compacted it should be dampened.

Filling should be done in layers not exceeding 12 in. in thickness and material so used should be at least equal in quality to clean earth. Rolling the surface of the sub-grade cannot remedy the failure to properly compact a fill during the process of making it. Time alone can do this. Rolling can be counted on only to smooth out and compact that upper thin layer of earth which is disturbed in the rough grading operations and in trimming the sub-grade to shape. Practically all rollers on the market are satisfactory for sub-grade rolling and generally as good results can be obtained with a 5-ton roller as with a 10-ton one. In city streets where there are usually many old trenches, it is a good plan to use a three-wheel roller and not a tandem. The latter

may bridge these old cuts, many of which may have been improperly puddled or tamped whereas the relatively narrow rear wheels of a three-wheel roller sink into these soft spots, and then they can be remedied.

255. Checking the Sub-grade.—On state roads, and also within city limits, on suburban and park roads of uniform cross-section for long uninterrupted distances, the elevation of the sub-grade can be readily checked by using a template riding on the side forms. The development of sub-graders, as illustrated in Fig. 115, not only insures an accurate sub-grade for country roads but also saves labor. These

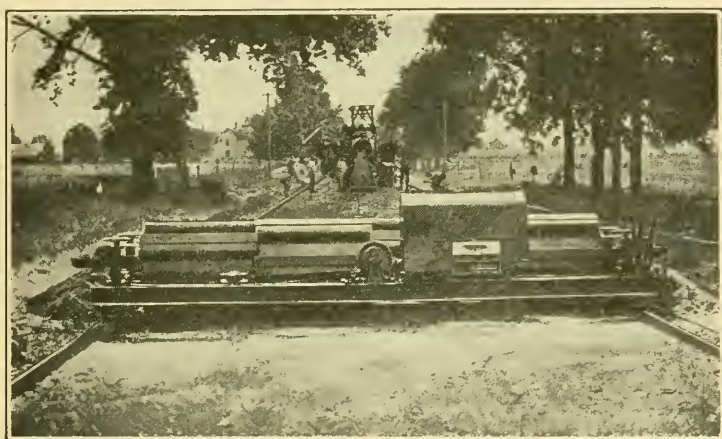


FIG. 115.—Sub-grader trimming roadbed for suburban pavement.

machines are capable of trimming to a depth of several inches. A belt conveyor operating inside the drums, around which the digging buckets are fixed, carries the excavated material to either side of the road outside the forms. Forward movement is obtained by means of anchored cables which are wound on drums on the machine. There are also other types of grades, fitted with blades which scrape or shave the sub-grade, but in general no type of machine can be used on city streets because of their great widths, their unsymmetrical crowns and frequent intersections.

Too often the "peg method" is depended upon when trimming the sub-grade by hand, the grade between pegs being determined by the eye. Cores, as illustrated in Fig. 116, taken from many pavements, the sub-grades of which were thus prepared, show

that in spots the pavements are too thin and in others too thick. Construction should be done, not to an average thickness, but to a minimum thickness. Any method of checking the sub-grade, however, should make sure not only that the public obtains a pavement of full thickness, but also that the contractor is not forced to lay an excessive thickness. Good results have been obtained by the use of screeds made of timbers 5 ft. long and 4 by 6 in. in cross-section, in the case of 6-in. pavements for instance. As shown in Fig. 117, these timbers can be laid true to grade on any cross-section and the sub-grade checked with a



FIG. 116.—Cores taken from a pavement the sub-grade of which was inaccurately trimmed. The center core (6 in.) shows the specified pavement thickness.

template. The grading men should keep far enough in advance of the other work on the street so as not to interfere with construction of the pavement. The timber should be left in place so that the screeders in the concrete gang may use them for guiding their strike board in bringing the concrete to grade.

Figure 118 illustrates the use of a template in checking the sub-grade in sidewalk construction.

256. Labor on Sub-grade.—If rough grading has been done with fair accuracy, it will be found that two men can place grade timbers or other forms and trim the sub-grade with sufficient rapidity to keep in advance of a one-bag mixer. For larger mixers, more men are necessary, though not in direct proportion; for instance, a four-bag mixer generally requires but four men.

However, if rough grading has been poorly done many more men may be required to handle the earth to be removed.



FIG. 117.—Checking the sub-grade, using a template riding between 4 × 6-in. timber screeds.

257. Laying Concrete Base.—Concrete for base construction, being a lean mix and not needing a fine surface finish, requires



FIG. 118.—Trimming to accurate grade, for a sidewalk.

only to be well rammed and true to grade with a fairly smooth surface. These results can be obtained by using a strike board

as shown in Fig. 119, the weight of which depends upon the consistency of the concrete. The drier the mix the heavier the board. The one in the photograph is 14 ft. long, is steel shod and weighs 200 lb. The sub-grade should always be dampened, since dry soil beneath robs the concrete of water.

In using the strike board, its rear end rides on the concrete previously brought to grade, while in the forward position it rides on the screed timbers set by the grading men. The concrete should be spread just a little above the proper grade so that as the strike board is moved forward with a sawing motion it screeds the concrete down to the approved thickness. The base is generally

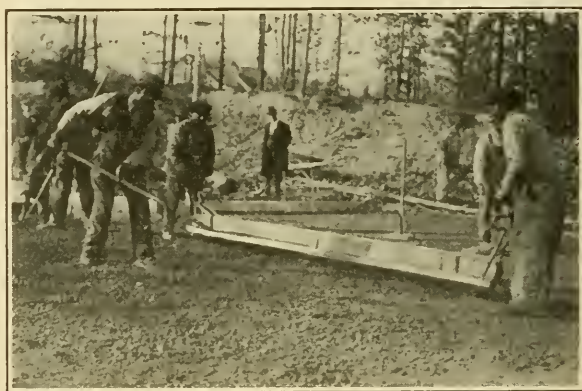


FIG. 119.—Tamping a concrete base with a 200-lb., 14-ft. strike board.

laid in 12-ft. sections extending cross-wise of the street. In moving forward the rear grade timbers are removed, concrete is deposited against the face of the work thus exposed, and tamped and spaded into place by the laborers, thus combining into one slab the concrete of the two sections. All work around manholes, etc. should be well spaded. At the end of a day's work and whenever work is held up for sufficient time for the concrete to set, it should be well spaded against the grade timbers, so that when they are removed there will be a clean vertical face against which the new work may be tamped thus giving a strong compression joint. In addition to the two-strike board men, there should be, for shovelling and spreading concrete, about one man per 100 sq. yd. of 6-in. base laid per day.

258. One Course Roadway.—Laying and screeding concrete in one course work is carried out practically as in base construction.

The concrete is richer and has to be wet enough to permit its being brought to a smooth non-porous wearing surface without an unreasonable amount of labor. Figure 120 shows work on a 30-

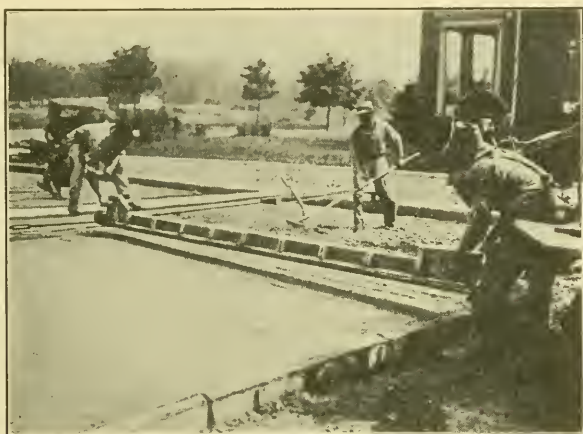


FIG. 120.—Screeding on a 30-ft. roadway, the front end of the 150-lb. strike board riding on screed timbers, the rear end on the concrete. The rear end is handled from a bridge.

ft. roadway. Screed timbers are used cross-wise of the street. In order to keep the rear strike board man off the concrete, a bridge is placed from curb to curb. On very wide streets and on



FIG. 121.—Screeding a pavement intersection where the expanse is so broad that a bridge cannot be used.

intersections, the bridge is not used but instead a 2 by 12-in. plank, as shown in Fig. 121, and the depression made in the green concrete by this plank is smoothed out as it is moved toward the curb.

259. Finishing Machines.—On roads of limited width and having long stretches of symmetrical cross-section, finishing machines as illustrated in Fig. 122 have been used with success, thereby saving labor and permitting the use of a relatively dry mix. The machine strikes off the concrete, tamps it and gives the final finish by belting the surface. Some machines that have been used have been so heavy as to deform the crown and produce an uneven surface. In any case, for a finishing machine, the side forms must be of steel and of heavy section.

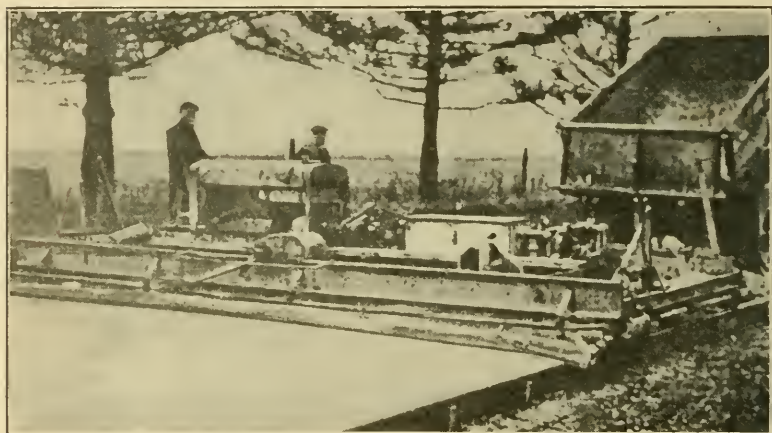


FIG. 122.—Finishing machine on 18-ft. concrete roadway.

260. Finishing One Course City Roadways.—To meet the varied conditions of city pavements, equipment for bringing the concrete to approved grade is limited practically to screed timbers and the strike board. The surface obtained by screeding should show little or no excess water and should have a rich mortar like appearance. This surface is improved and any tendency to porous spots may be ironed out as shown in Fig. 123, by using a light roller which also draws out any excess water that may be in the surface. On narrow roadways, one man may operate the roller with a long handle. On wider roadways, two men, one on either side, pull the roller back and forth by means of a rope. The roller should be approximately 6 ft. long, be made of about 14-gauge iron, and have a diameter of about 10 in. It should weigh close to 60 lb. Rolling may usually follow the screeding by $\frac{1}{2}$ hr. and should be repeated at short intervals until each section has been rolled three times.

The final finish on country roads is usually obtained with a long 8 or 10-in. wide composition belt which is pulled back and forth over the surface. This method does not give good results on



FIG. 123.—Rolling the surface.

wide city streets on account of the extreme weight of the long belt necessary and also on account of interference by the curbs. A satisfactory finish is obtained, and with little trouble, by using



FIG. 124.—The job is finished by dragging longitudinally with a $1\frac{1}{2}$ -in. rubber hose.

a hose as shown in Fig. 124. The diameter of the hose is $1\frac{1}{2}$ in. and it is filled with water (the ends being plugged) in order to give it added weight. Dragging the surface in this manner smooths out the tiny ridges in the mortar remaining after rolling and also

takes away any water that may be on the surface. The two men that handle the roller also use the hose.

Finishing one course concrete roadways is no difficult matter if the concrete is properly proportioned and has the proper consistency. This is more important than the method of finishing. After the strike board has been used, the surface should appear to be neither too dry nor too wet. It should not be necessary to sprinkle the pavement with dry cement as is often done, nor, if the roller and hose are properly used, to use hand floats and trowels, except around manholes, catch basins, inlets and places that cannot be reached otherwise.



FIG. 125.—Taking out the steel dividing strips thus leaving the walk divided into small blocks.

261. Two Course Sidewalk.—The construction of the base for a sidewalk differs from that for a roadway as it has to be divided into small blocks. This can be accomplished by constructing the pavement, both topping and base, in alternate sections, waiting for one group of sections to set prior to placing the intermediate ones. Also forms such as those shown in Fig. 125 may be used, the dividing strips being pulled just before the walk, topping and base inclusive, has its set. An economical method, and it is simple in application no matter how wide the walk may be, is to divide the base into squares, generally 3 ft. on a side, with a “razor” as shown in Fig. 126. These divisions extend clear through the base and are filled with sand.

The topping (proportions commonly specified range from 1:1½ to 1:2) should be placed on the base as soon as possible. The



FIG. 126.—Cutting divisions into the base for sand joints.



FIG. 127.—Screeding the 1-in. mortar top.

interval should be not greater than 40 min. In order to insure 1 in. of topping the mortar should be struck off, as shown in Fig.

127, with a board riding on 1-in. mortar screeds laid on the base. After screeding, the surface is dusted with a drier, mixed in the proportion of 1 part sand (passing a No. 86 sieve) and 1 part



FIG. 128.—Floating the drier.

cement, and containing such tinting matter as may be desired ($1\frac{1}{2}$ lb. of lamp black per bag of cement is commonly used). The drier is rubbed into the surface with a trowel or wooden float as shown in Fig. 128. The pavement is then laid out in



FIG. 129.—Laying out the pavement into squares, using jointing tools.

squares, Fig. 129, and joints worked into the surface with jointing tools. The blade of the jointer extends down into the surface only about $\frac{1}{4}$ in. which is sufficient since these joints are directly over the sanded ones of the concrete base. The final finishing is

obtained by troweling as in Fig. 130. A gang of finishers can complete from 5 to 10 sq. yd. of pavement per man per hour, the amount depending upon the efficiency of the men. Their work includes mixing the drier, dusting, marking into squares, and all allied operations and the final troweling.

262. One Course Walk.—The construction of one course sidewalk is similar to that of one course roadway, as far as screeding. Thereafter, the work is similar to that of two course walk. With a narrow walk the strike board may rest on the side forms and the concrete is screeded lengthwise of the pavement as illustrated in Fig. 131. Where the walk is wide or structures



FIG. 130.—The final troweling of the surface.

abut it, transverse screeds have to be used and the work proceeds as with roadways. It is advantageous to be liberal with the drier or dusting coat in order to speed up finishing operations and facilitate marking the surface into squares. Instead of using a 1:1 dusting mixture as with mortar top construction, a larger proportion of sand may be used, and with not much increase in the amount of coloring matter per bag of cement. The mixture should be dusted on the surface immediately after screeding. If the concrete mix is too wet, it will be found that an unreasonable amount of drier has to be used and time will be wasted waiting for the surface to dry. When insufficient water is used there will be great difficulty in properly finishing the walk. If the concrete proportions are well chosen and the proper consistency is used it

will be found that a finish satisfactory in every respect can be obtained rapidly and economically.

With a one-bag mixer as shown in Fig. 131, a small but well-



Fig. 131.—A steel shod 100 lb. strike board, $6\frac{1}{4}$ ft. long. The one course walk is struck off lengthwise of the pavement, the side forms serving as screeds.

organized gang can construct about 200 sq. yd. of 4-in. pavement in an 8-hr. day, in which case operating costs are as follows:

TABLE XXVIII.—MIXING AND PLACING CONCRETE

1 operator.....	@ 50 cts. per hour	\$ 4.00
4 gal. gasoline.....	@ 25 cts. per gallon	1.00
Mixer charges.....		5.00
1 man for sand.....	@ 40 cts. per hour	3.20
2 men for gravel.....	@ 40 cts. per hour	6.40
1 man for cement.....	@ 40 cts. per hour	3.20
2 men on strike board.....	@ 50 cts. per hour	8.00
1 man spreading.....	@ 40 cts. per hour	3.20
Cost for 200 sq. yd.....		\$34.00
Mixing and placing, per square yard.....		0.17

Rough grading should be carried out well ahead of concreting. Trimming the sub-grade accurately and setting forms should proceed immediately ahead of the mixer. Some of the men in the trimming gang should be qualified finishers, working on the sub-grade in the morning and on finishing in the afternoon. This gang should also help out on any odd jobs arising during the day.

Data for trimming the sub-grade, setting forms and finishing the surface are as follows:

TABLE XXIX.—TRIMMING SUB-GRADE, FORMS AND FINISHING

1 Finisher.....	@ 70 cts. per hour	\$5.60
1 Form setter.....	@ 60 cts. per hour	4.80
3 Utility men.....	@ 55 cts. per hour	13.20
2 Laborers.....	@ 40 cts. per hour	6.40

Cost for 200 sq. yd.....\$30.00

Sub-grade, forms and finishing, per square yard 0.15

The question of finishing one course walk is of particular interest. On the job illustrated the 6-ft. walk was marked transversely with jointing tools at 6-ft. intervals (with one course construction division into 3-ft. blocks is unnecessary). For the dusting coat $3\frac{1}{2}$ cu. ft. of sand, $1\frac{3}{4}$ bags of cement and 4 lb. of lamp black were used per 100 sq. yd. of pavement. The finishing gang in mixing the drier, dusting the surface and finishing the pavement had no difficulty averaging 7 to 8 sq. yd. of pavement per man per hour.

The promiscuous cracking of one course walk can be prevented by constructing it in alternate sections or by using steel dividing strips which are later pulled, as was described under two course construction. Generally, if the slabs contain no more than 20 sq. yd., random cracks need not be expected, and the narrower the walk the larger the slab area may be. Continuous 6-ft. walks have been laid with few or no cracks subsequently appearing. Placing regularly spaced joints in concrete pavements adds to the expense of construction and even when the work is carefully done trouble eventually appears due to slipping or buckling of the slabs at the joints. Cracks are not particularly objectionable, they do not inconvenience the pedestrian, and they are not uncommon in the mortar topping of two course sidewalk. Accordingly it is unreasonable to take extensive steps to eliminate them in one course construction.

263. Exposed Aggregate Walk.—Around monumental buildings and in other special locations, walks with exposed aggregate finish are often used in order to obtain a decorative effect through the tone and texture of the surface. For this work two course construction is generally necessary and selected aggregate is used in the mortar topping. With screened coarse sand, the grains

ranging in size from $\frac{1}{8}$ to $\frac{1}{4}$ in., and proportioned 1 cement: 2 sand, a good effect may be obtained economically. Within 24 hr. after the topping is trowelled to an even surface it is scrubbed with a stiff brush and water. In case difficulty is had in properly exposing the aggregate a solution of 1 part hydrochloric acid in 4 parts of water by volume may be used in place of water. After exposing the aggregate, all traces of acid should be removed by thorough washing with a hose.

Crushed marble, granite, quartz, feldspar, or other stone of specially selected colors may be used in the topping. For the

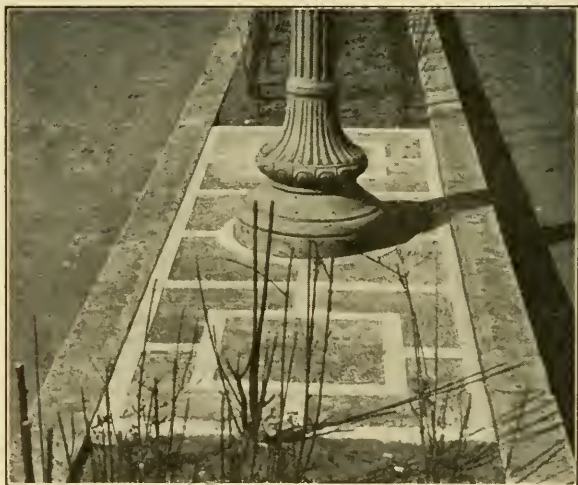


FIG. 132.—Exposed aggregate finish.

surface illustrated in Fig. 132 the mortar was proportioned, one bag of white cement, $\frac{1}{2}$ cu. ft. white sand, $\frac{3}{4}$ cu. ft. black grits and $\frac{3}{4}$ cu. ft. red grits. The decorative design was obtained by using a form cut from heavy tin. This form was laid on the surface, thus outlining and protecting the borders, shown in white in the photograph, while the finishers scrubbed between them.

264. Concrete Curb.—Principles affecting the choice of materials for curbing along roadways were set forth under "Curb," Chap. V; also the question of dimensions was discussed. An 8 by 8-in. curb of concrete, equal in quality to that used for one course pavement, bedded on a concrete foundation 16 in. wide and 6 in. deep, will give good service. The foundation may be of lean concrete, about equal to that used for roadway base.

Concrete curb may be precast, in which case sections should be no longer than 6 ft. in order not to exceed a weight satisfactory for handling. If cast in place sections up to 10 ft. may be used, the sections being formed with division plates which are pulled just before the concrete finally hardens. Strong forms that will not warp should be used, for curb that is not true to line and grade is very unsightly. There are a number of metal forms on the market that are excellent for curb construction. Metal forms also, that are useful in constructing curb integrally with the roadway or with narrow concrete gutters.

Concrete should be well spaded against the forms and given a top finish without the use of additional mortar. Upon removal of the forms no plastering should be necessary. The top edge facing the roadway should be rounded slightly, using a radius of



FIG. 133.—Lawn sprinklers used for curing concrete pavement.

about $\frac{1}{2}$ in. Metal guards, to be cast in the concrete, can be obtained for the protection of this edge. Satisfactory results, however, can be obtained without such guards.

265. Curing.—Under the heading “Curing Test Pieces” Chap. IX, there was shown the necessity of keeping concrete in a moist condition throughout a short curing period. The length of this period depends upon climatic conditions and the requirements of travel. Most specifications require that the pavement shall be cured at least 18 days prior to opening it for use. It is important that the concrete attain a considerable portion of its ultimate strength prior to permitting the passage of heavy loads over it. For concrete base it is customary to exclude heavy

loads for 6 or 7 days which accordingly usually means that the surface cannot be laid for that period.

Maintaining the concrete in a damp or wet condition reduces the formation of promiscuous cracks. This is desirable in one course roadway construction, not so important in the case of bases and of greater importance in one course sidewalk work. Surface checking takes place often to a considerable extent, during the first 12 hr. after laying the pavement, due to too rapid drying out. If clean, damp burlap is spread on the green surface and kept moist, this surface checking can be practically eliminated. This burlap can be removed the following morning and if it has been used carefully, there should be no objectionable marking of the surface. In any case it is a good plan to have burlap or other material on hand in order to cover the pavement surface as a protection if a sudden shower occurs. Many square yards of green surface have been ruined by rain. Beginning the morning following the laying of the concrete various methods have been used for curing, as for instance, ponding, covering with wet earth, and sprinkling with calcium chloride. The use of lawn sprinklers as illustrated in Fig. 133, is economical, and in addition, being a clean method it is a minimum nuisance to abutting property owners. The sprinklers in most climates need be operated only during the hours between sunrise and sunset.

266. Cold Weather Concreting.—Undoubtedly concrete pavements can be constructed under freezing conditions, but extra expense is necessary to assure success. Also there is always the risk that some of the precautions necessary may be neglected. Before the working season opens in the spring a plan of progress should be mapped out calling for completion of all concrete work before cold weather sets in. If at any time work falls behind the schedule it is better to catch up while proceeding with the remainder of the schedule than to depend upon working during cold weather.

Low temperatures retard and high ones accelerate the setting of concrete. In freezing weather the aggregates and water should be heated so that the concrete as deposited will have a temperature of about 80°F. Aggregates may be heated in the same manner as for bituminous mixtures, while the water may be heated by any ordinary method giving temperatures of from 150 to 180°F. The use of special ingredients was discussed in Chap. X. The mistake should not be made of using as a protective

measure sodium chloride (common salt) in place of calcium chloride. Sodium chloride lowers the freezing point, but it also seriously retards the setting of cement.

As soon as possible after laying the pavement it should be covered with canvas. In very cold weather the canvas should be stretched on frames so that heat can be supplied beneath it. After the concrete has its initial set it should be covered with straw held in place by a covering of canvas. Manure used in place of straw may stain the surface badly and may cause, according to some engineers, pitting and scaling of the concrete.

267. Cost Data.—Costs depend upon those elements which have thus far been discussed; transportation, mixing layouts, and methods of construction. In addition there is the factor “efficiency of labor.” When men are hard to find and the highest rates per hour have to be paid, labor is least efficient. For instance, instead of a man loading his barrow and wheeling it to the mixer, an additional man has to be hired to load the barrow. The data in the accompanying table can show only in a general way the form that estimates should take. The accuracy of an estimate depends upon the care and judgment exercised by the engineer, and upon the correctness of the details which make up the separate items shown in the table, not only definite ones such as handling materials or mixing, but also that very indefinite item “over-head and contingencies.”

268. Maintenance.—In Chap. V, it was mentioned that concrete pavements can be easily and successfully repaired. Some persons have advocated the use of bituminous materials for patching concrete pavements, but such materials should be used only in case of emergency. A concrete patch if properly made becomes a permanent fixture and makes the riding surface as good as new.

In Fig. 134, air drills are shown cutting out a defective area in a concrete pavement. Air drilling is well adapted to this class of work. To break concrete by hand is slow and expensive and usually heavy sledges are used which rack the adjacent pavement thus leading to further deterioration. The stronger and thicker the concrete the more economy there is in the choice of air drills over hand methods. The pavement shown in the photograph is but 4 in. in thickness. By hand, 1.7 sq. yd. were taken out per man per hour. By air 1.8 sq. yd. were cut per drill per hour.

TABLE XXX.—SIDEWALK AND ROADWAY ESTIMATES, PER SQUARE YARD

Items	4-in. one course walk	5-in. two course walk	6-in. base	6-in. roadway
Gravel @ \$1.20 ton.....	250 lb. \$0.15	270 lb. \$0.16	405 lb. \$0.24	375 lb. \$0.23
Sand @ 75 cts. ton.....	162 lb. 0.06	108 lb. 0.04	162 lb. 0.06	243 lb. 0.09
Cement @ \$2.50 bbl.....	62 lb. 0.41	50 lb. 0.33	70 lb. 0.50	93 lb. 0.62
Concrete materials.....	(1:2¼:3%) \$0.62	(1:2:5) \$0.53	(1:2:5) \$0.80	(1:2¼:3%) \$0.94
Sand @ 75 cts. ton.....	.....	80 lb. 0.03	.....	.....
Cement @ \$2.50 bbl.....	.....	42 lb. 0.28	.....	.....
Mortar materials.....	.....	(1:1½) 0.31	.....	.....
Sand @ 75 cts. ton.....	4 lb. 0.002	2 lb. 0.001	.....	.....
Cement @ \$2.50 bbl.....	2 lb. 0.013	2 lb. 0.013	.....	.....
Lamp black @ 15 cts. lb.....	0.05 lb. 0.007	0.03 lb. 0.005	.....	.....
Surface materials.....	0.02	0.02	.....	.....
Hauling @ 60 cts. ton.....	483 lb. 0.14	554 lb. 0.17	637 lbs 0.19	711 lb. 0.21
Materials on job.....	0.78	1.03	0.99	1.51
Trimming and forms.....	0.05	0.05	0.04	0.04
Handling to mixer.....	0.07	0.07	0.10	0.10
Mixer and plant charge.....	0.07	0.07	0.05	0.05
Working concrete.....	0.06	0.07	0.09	0.09
Total for concrete.....	0.25	0.26	0.28	0.28
Handling to mixer.....	.....	0.03	.....	.....
Mixer and plant charge.....	.....	0.03	.....	.....
Working mortar.....	.....	0.04	.....	.....
Total for mortar.....	.....	0.11	.....	.....
Finishing surface.....	0.10	0.10	.....	0.02
Total job costs.....	1.13	1.50	1.27	1.45
15 per cent cont. and overhead.....	0.17	0.23	0.19	0.22
15 per cent profit.....	0.17	0.23	0.19	0.22
Estimate per square yard.....	1.47	1.96	1.65	1.89

A 6-in. patch is to be placed in the old 4-in. pavement shown in Fig. 134, because it is worth while to establish the general policy that no concrete, either in original pavement or in patches should be less than 6 in. in thickness. The sub-grade and edges of the surrounding concrete should be moistened prior to putting in the patch. The fresh concrete should be a rather dry mix so that considerable tamping will be required in order to obtain a satisfactory surface finish. The concrete should be well spaded against the edges of the adjacent pavement.



FIG. 134.—Cutting out, with air drills, concrete pavement for patching.

269. Joints and Cracks.—It is important to keep all joints and cracks in concrete roadways well sealed, as otherwise the edges of the abutting slabs spall and break down under traffic until eventually a worn and broken area of considerable magnitude develops. Bituminous material used for sealing joints may be any of a large variety of products on the market. Fillers for block pavements (see Chap. XVIII) are excellent, though any of the products common to bituminous roadway practice may be adapted to sealing cracks in concrete, even cut backs and emulsions which are used without melting or heating.

The general principles set forth in Chap. XVIII, should be followed in using bituminous cement filler. Crevices in the concrete should be cleaned with a stiff brush or broom. Compressed air is sometimes used for blowing out loose particles and dirt. Using large smears of filler is not only wasteful but also

gives unsightly results. No more should be poured along a crack than required to seal it and protect the edges of the concrete. A slight covering of coarse sand should be applied immediately. An animal-drawn cart carrying sand and whatever else may be necessary, with a kettle on wheels trailing behind and containing the bituminous material makes a handy outfit for crack maintenance.

The Bureau of Public Roads has developed a compound of rubber, petroleum oil, pine rosin and mineral filler with the idea of producing a white crack filler thus eliminating unsightly black streaks across pavements. A successful product of this nature would be particularly desirable for use on one course sidewalks.

PART IV
BITUMINOUS PAVING

CHAPTER XIV

BITUMINOUS MATERIALS AND TESTS

270. General Characteristics.—There are two main classes of bituminous materials used for paving—asphalts and tar products. In the manufacture of each class two materials are handled—distillates and residues. The latter range from liquids to solids, and for paving work must possess good binding qualities and whether soft or hard should not volatilize excepting those for use without heating or readily deteriorate when used in the roadway. While a residue may be manufactured to a desired degree of hardness, it is sometimes necessary to obtain the desired degree at the paving plant by combining varying quantities of soft and hard bitumens. Asphaltic petroleum are often hardened without material distillation by blowing air through them at proper temperatures. Some asphalts exist in a native solid state corresponding to hard residues, others are found mixed with fine mineral matter, sand, shale etc.

For bituminous pavement mixtures and for construction by the penetration method, the materials used, whether asphalts or tar products, are of such solidity as to be non-workable at ordinary temperatures. They are brought to a fluid state by heating. Tar liquids for cold surface treatment are usually straight run products, for cold patching they are usually residues cut back with distillates. Asphalts for cold work are usually cut backs. The light oils in bituminous materials that are used cold have no binding qualities and should rapidly volatilize leaving the residues in the pavements. Sometimes, instead of distillates, a saponifying agent or soap is added to asphaltic bitumens so that they may be rendered liquid by the addition of water and then used for surface treatment or cold patching.

271. Definitions.—The following definitions are extracted from the American Society for Testing Materials Standard, D8-18.

Relating in General to Bituminous Materials

Bitumens.—Mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulfide.

Bituminous.—Containing bitumen or constituting the source of bitumen.

Bituminous Emulsion.—A liquid mixture in which minute globules of bitumen are held in suspension in water or a watery solution.

Cut-back Products.—Petroleum or tar residuums which have been fluxed with distillates.

Flux.—Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.

Liquid Bituminous Materials.—Those having a penetration at 25°C. (77°F.) under a load of 50 g. applied for 1 sec., of not more than 350.

Solid Bituminous Materials.—Those having a penetration at 25°C. (77°F.), under a load of 100 g. applied for 5 sec., of not more than 10.

Relating Specifically to Petroleums or Asphalts

Asphalts.—Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Artificial Asphalt.—Recommended that the use of term be discontinued.

Asphalt Cement.—A fluxed or unfluxed asphalt specially prepared as to quality and consistency for direct use in the manufacture of bituminous pavements, and having a penetration at 25°C. (77°F.) of between 5 and 250, under a load of 100 g. applied for 5 sec.

Liquid Asphalt.—This is a trade term not subject to definition.

Native Asphalt.—Asphalt occurring as such in nature.

Road Asphalt.—This is a trade term not subject to definition.

Rock Asphalt.—Sandstone or limestone naturally impregnated with asphalt.

Petroleum.—Liquid bitumen occurring as such in nature.

Blown Petroleums.—Semi-solid or solid products produced primarily by the action of air upon liquid native bitumens which are heated during the blowing process.

Topped Petroleum.—Petroleum deprived of its more volatile constituents.

Asphaltenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements and solid native bitumens, which are soluble in carbon disulfide but insoluble in paraffin naphthas.

Carbenes.—The components of the bitumen in petroleum, petroleum products, malthas, asphalt cements and solid native bitumens, which are soluble in carbon disulfide but insoluble in carbon tetrachloride.

Relating Specifically to Tars and Pitches

Tars.—Bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyrobitumens or organic materials.

Coal Tar.—The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.

Gas-house Coal Tar.—Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Coke-oven Tar.—Coal tar produced in by-produce coke ovens in the manufacture of coke from bituminous coal.

Oil-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of oil gas.

Water-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of carburetted water-gas.

Dehydrated Tars.—Tars from which all water has been removed.

Refined Tar.—Tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency; or a product produced by fluxing tar residuum with tar distillate.

Dead Oils.—Oils with a density greater than water which are distilled from tars.

Pitches.—Solid residues produced in the evaporation or distillation of bitumens, the term being usually applied to residues obtained from tars.

Straight-run Pitch.—A pitch run to the consistency desired, in the initial process of distillation, without subsequent fluxing.

Free Carbon in Tars.—Organic matter which is insoluble in carbon disulfide.

Relating Specifically to Tests

Normal Temperature.—As applied to laboratory observations of the physical characteristics of bituminous materials, is 25°C. (77°F.).

Consistency.—The degree of solidity or fluidity of bituminous materials.

Fixed Carbon.—The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.

Penetration.—The consistency of a bituminous material expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. Where the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 g., 5 sec., and 25°C.

(77°F.), respectively, and the units of penetration to indicate hundredths of a centimeter.

Viscosity.—The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given amount of the material through a given orifice.

272. Methods of Sampling.—The following specifications for the sampling of bituminous materials are American Society for Testing Materials Tentative Methods, D140-22T.

1. GENERAL DIRECTIONS.—Samples may be taken for either of two purposes:

(a) To represent as nearly as possible an average of the bulk of the material sampled.

(b) To ascertain the maximum variation in characteristics which the material may possess. In either case they shall be obtained by methods hereinafter described.

2. (a) Care shall be taken that the samples are not contaminated with dirt or any other extraneous matter and that the sample containers are perfectly clean and dry before filling.

(b) Immediately after filling, the sample containers shall be tightly closed and properly marked for identification on the container itself or on a linen tag attached to the container.

3. TIME AND PLACE.—(a) Whenever practical, bituminous materials shall be sampled at the point of manufacture, and at such time as to allow the tests, controlling acceptance or rejection, to be made in advance of shipment.

(b) When impracticable to take samples at the point of manufacture, they should be taken from the shipment immediately upon delivery.

4. SIZE OF SAMPLES.—For routine laboratory examination of acceptability of a given lot, not less than 1 qt. of material should be submitted which should be representative of the average sample collected as hereinafter described.

5. CONTAINERS.—Containers for liquid bituminous materials shall be small-mouth cans with cork-lined screw caps. Containers for semi-solid and solid materials shall be friction top cans.

SAMPLING AT PLACE OF MANUFACTURE

6. FROM BULK STORAGE.—The inlet and outlet to the storage tank shall be sealed and a 1-gal. sample drawn from the top, middle and bottom contents. The sample may be taken from drain cocks on the side of the tank, if such are available. Enough material should be discarded to insure a representative sample. Otherwise, samples may be

taken by lowering weighted bottles or cans into the material. The bottle or can should be fitted with a stopper which can be removed by a string or wire attached to it after it has been lowered to the proper depth. The three samples from bulk storage shall be tested separately for consistency in order to detect stratification. They may then be combined and thoroughly mixed for other tests that may be required.

7. *SAMPLING DURING LOADING.*—Where tank cars, distributors or barrels are being filled, samples may conveniently be taken from the pipe line through which the material is flowing, as hereinafter described.

8. (a) *WHEN MATERIAL IS PUMPED UNDER PRESSURE.*—The sampling pipe shall be inserted into a rising section of the pipe line on the discharge side of the pump. The sampling pipe shall be not more than one-eighth the diameter of the line pipe and its opening should be turned at an angle of 90 deg. facing the flow of the liquid. This pipe shall be provided with a plug cock and shall discharge into a receiving drum of 50-gal. capacity. The plug cock shall be so adjusted that there is a steady continuous flow of bituminous material through it and shall be so regulated that the receiver will fill in the same time that is required to make the entire pumping. In the case of semi-solid materials, the receiver shall be provided with a steam coil which shall keep the contents at a temperature just above the liquefying point. At completion of the pumping, the receiver shall be thoroughly agitated, and a 1-qt. sample taken therefrom. The sampling shall be so regulated that for 1,000 gal. of material pumped, at least 1 gal. of sample is taken; but 40 gal. shall be the limit required for any one cargo.

Care should be taken that the drip cock, after once having been set, allows a constant flow during the pumping.

This method is also applicable to gravity flows where the pipe line is completely filled by the outflowing liquid and has a rising section.

9. (b) *WHEN MATERIALS FLOW BY GRAVITY.*—Materials flowing by gravity through pipes which are not completely filled may be sampled by taking dipperfuls at the outlet at frequent and regular intervals. These samples shall be combined and the total sample shall be not less than 0.1 per cent of the whole material. The samples shall be collected in a receiver and resampled as described in Sec. 8.

SAMPLING AT POINT OF DELIVERY

10. *TANK CARS.*—Samples may be taken by means of a weighted bottle or can, as described in Sec. 6, or from the unloading pipe line as described in Sec. 7.

Liquid bituminous materials shall be sampled before heating. Semi-solid or solid bituminous materials shall be rendered fluid by heating. Sampling should be so conducted as to eliminate the possibility of adventitious water resulting from leaky steam heating coils, rain or snow.

11. **DISTRIBUTORS.**—Samples may be taken from distributors by means of a weighted bottle or can, as described in Sec. 6. One sample shall be sufficient.

12. **BARRELS AND DRUMS.**—(a) Samples of liquid bituminous materials from barrels or drums may be secured by taking 1 qt. of material from one out of every 10 packages, combining and thoroughly mixing these samples and then removing an average sample from the combined material.

(b) Sampling of solid or semi-solid materials from barrels is more difficult to accomplish properly. It is recommended that samples be taken from each car lot, but if this sample fails to meet the specification requirements, then a sample shall be taken from each batch represented or from 1 out of each 20 bbl., samples to be taken from at least 3 in. below the surface and at least 3 in. from the side of the barrel. A clean hatchet may be used if the material is hard enough to shatter and a broad stiff putty knife if the material is soft. The samples so taken shall be melted and thoroughly mixed and an average sample taken from the combined material for examination.

273. Penetration Test.—The Penetration Test is made on semi-solid and solid asphalts but seldom on tar products because they are generally too soft. This and other consistency tests to be described are important since they control the fluidity or degree of hardness, as the case may be, of materials to be used. In hot mix work when the cement is kept at elevated temperatures for long periods regular testing is necessary, so that, as the product hardens, more flux may be added as required. By running the Penetration Test at 32°F. and 115°F. the susceptibility of different bituminous substances to temperature changes may be compared. Blown petroleum asphalts show less susceptibility to temperature changes than do straight residual asphalts which in turn show less than tar residues. In drawing up specifications it should be realized that an unwarranted hardship is placed upon the manufacturer if penetrations are stipulated too narrowly. For asphalts of less than 90 penetration a 10-point limit may be permitted and for cement of over 90 penetration a still larger limit up to 30 points for 150 penetration. The American Society for Testing Materials Standard Method, D5-21, for the Penetration Test is as follows:

1. **CONTAINER.**—The container for holding the material to be tested shall be a flat-bottom, cylindrical dish, 55 mm. ($2\frac{3}{16}$ in.) in diameter and 35 mm. ($1\frac{3}{8}$ in.) deep.

NOTE.—This requirement is fulfilled by the American Can Company's Gill style ointment box, deep pattern, 3-oz. capacity.

2. NEEDLE.—The needle, Fig. 135, for this test shall be a cylindrical steel rod 50.8 mm. (2 in.) long, having a diameter of 1.01 to 1.02 mm. and having a taper of 6.34 to 6.36 mm. measured on the axis. After

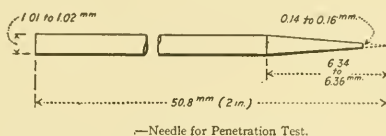


FIG. 135.—Needle for penetration test.

tapering, the point shall be "blunted" by grinding off to a truncated cone, the smaller base of which shall be from 0.14 to 0.16 mm. in diameter.

3. WATER BATH.—The water bath shall be maintained at a temperature not varying more than 0.1°C . from 25°C . (77°F .). The volume of water shall be not less than 10 l. and the sample shall be immersed to a

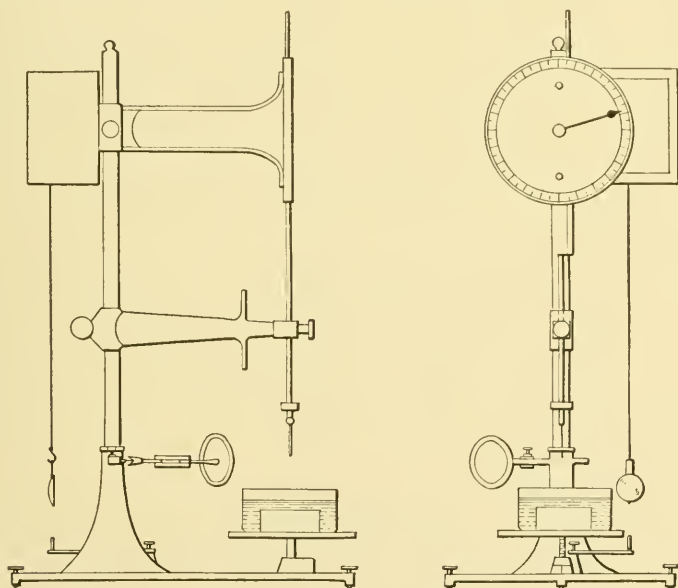


FIG. 136.—"Penetrometer." A type of apparatus for the penetration test.

depth of not less than 10 cm. (4 in.) and shall be supported on a perforated shelf not less than 5 cm. (2 in.) from the bottom of the bath.

4. APPARATUS FOR PENETRATION.—Any apparatus which will allow the needle to penetrate without appreciable friction, and which is accurately calibrated to yield results in accordance with the definition

of penetration, will be acceptable. A type commonly used is illustrated in Fig. 136.

5. **TRANSFER DISH FOR CONTAINER.**—The transfer dish for container shall be a small dish or tray of such capacity as will insure complete immersion of the container during the test. It shall be provided with some means which will insure a firm bearing and prevent rocking of the container.

6. **PREPARATION OF SAMPLE.**—The sample shall be completely melted at the lowest possible temperature and stirred thoroughly until it is homogeneous and free from air bubbles. It shall then be poured into the sample container to a depth of not less than 15 mm. ($\frac{3}{8}$ in.). The sample shall be protected from dust and allowed to cool in an atmosphere not lower than 18°C. (65°F.) for 1 hr. It shall then be placed in the water bath along with the transfer dish and allowed to remain 1 hr.

7. **PROCEDURE.**—(a) In making the test the sample shall be placed in the transfer dish filled with water from the water bath of sufficient depth to completely cover the container. The transfer dish containing the sample shall then be placed upon the stand of the penetration machine. The needle loaded with specified weight, shall be adjusted to make contact with the surface of the sample. This may be accomplished by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light. Either the reading of the dial shall then be noted or the needle brought to zero. The needle is then released for the specified period of time, after which the penetration machine is adjusted to measure the distance penetrated.

At least three tests shall be made at points on the surface of the sample not less than 1 cm. ($\frac{3}{8}$ in.) from the side of the container and not less than 1 cm. ($\frac{3}{8}$ in.) apart. After each test the sample and transfer dish shall be returned to the water bath and the needle shall be carefully wiped toward its point with a clean, dry cloth to remove all adhering bitumen. The reported penetration shall be the average of at least three tests whose value shall not differ more than four points between maximum and minimum.

(b) When desirable to vary the temperature, time and weight, and, in order to provide for a uniform method of reporting results when variations are made, the samples shall be melted and cooled in air as above directed. They shall then be immersed in water or brine, as the case may require, for 1 hr. at the temperature desired. The following combinations are suggested:

At 0°C. (32°F.) 200-g. weight, 60 sec.

At 46.1°C. (115°F.) 50-g. weight, 5 sec.

274. Float Test.—In general it may be said that the Float Test fills the gap between the Penetration Test and the Viscosity

Determination. Its range is limited and it cannot be used with very fluid bituminous materials nor with very hard solids. The test is covered by the American Society for Testing Materials Tentative Method D139-22T, which follows:

1. APPARATUS.—*Float*.—The float shall be made of aluminum or aluminum alloy and shall be in accordance with the following requirements (see Fig. 137):

	MINIMUM	NORMAL	MAXIMUM
Weight of float, gram.....	37.80	37.95	38.10
Total height of float, millimeter.....	34.0	35.0	36.0
Height of rim above lower side of shoulder, millimeter.....	26.5	27.0	27.5
Thickness of shoulder, millimeter.....	1.2	1.4	1.6
Diameter of opening, millimeter.....	10.7	11.1	11.5
Height of rim above water with load of 5.5 g., millimeter.....	7.0	8.5	10.0

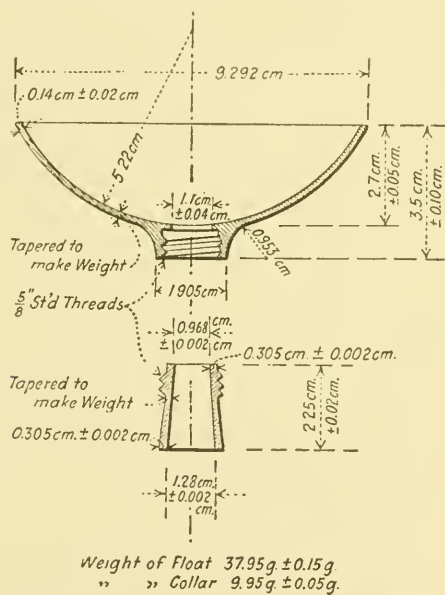


FIG. 137.—Float and collar for the float test

Collar.—The collar shall be made of brass and shall be in accordance with the following requirements (see Fig. 137):

	MINIMUM	NORMAL	MAXIMUM
Weight of collar, gram.....	9.90	9.950	10.00
Over-all height of collar, millimeter.....	22.30	22.50	22.70
Inside diameter at bottom, millimeter.....	12.78	12.80	12.82
Inside diameter at top, millimeter.....	9.66	9.68	9.70

Thermometer.—The thermometer shall conform to the following specifications:

Total length.....	370–400	mm.	(14.57–15.75 in.)
Diameter.....	6.5–7.5	mm.	(0.256–0.295 in.)
Bulb length.....	Not over 14	mm.	(Not over 0.55 in.)
Bulb diameter.....	4.5–5.5	mm.	(0.177–0.217 in.)

The scale shall be engraved upon the stem of the thermometer, shall be clear cut and distinct, and shall run from zero to 80°C. (32 to 176°F.) in 0.2°C. divisions. It shall commence not less than 75 mm. (2.95 in.) above the bottom of the bulb. The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of a suitable quality of glass and be so annealed as not to change its readings under conditions of use. It shall be correct to 0.25°C. (0.45°F.) as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the U. S. Bureau of Standards.

Bath.—The minimum diameter of the bath shall be twice the diameter of the float; the minimum depth of water shall be equal to the diameter of the bath.

2. PREPARATION OF SAMPLE.—The sample shall be completely melted at the lowest possible temperature, heating only sufficiently to bring the product into a fluid condition but not above 350°F., and stirred thoroughly until it is homogeneous and free from air bubbles.

The brass collar shall be placed with the smaller end on a brass plate which has been previously amalgamated with mercury by first rubbing it with a dilute solution of mercuric chloride or nitrate and then with mercury. The sample shall be poured into the collar in any convenient way until slightly more than level with the top. It shall be cooled to room temperature, placed in water maintained at 5°C. for 5 min., after which the surplus material shall be removed by means of a spatula or steel knife, which has been slightly heated. The collar and plate shall then be placed in tin cup containing ice water maintained at 5°C., $\pm$ 1°C., and left in this bath for at least 15 min.

3. PROCEDURE.—(a) The bath shall be filled with water and the water heated to the temperature at which the test is to be made. This temperature shall be accurately maintained and shall at no time throughout the test be allowed to vary more than 0.5°C. from the temperature specified.

(b) After the material to be tested has been kept in the ice water for not less than 15 min. nor more than 30 min., the collar with its contents shall be removed from the plate and screwed into the aluminum float and immersed in water at 5°C. for 1 min. Any water shall then be removed from the inside of the float and the latter immediately floated

in the warm bath. As the plug of material becomes warm and fluid, it is forced upward and out of the collar until the water gains entrance into the saucer and causes it to sink.

(c) The time in seconds between placing the apparatus on the water and when the water breaks through the material shall be determined by means of a stop watch, and shall be taken as a measure of the consistency of the material under examination.

Note.—Special precaution should be taken to insure the collar fitting tightly into the float and to see that there is no seepage of water between the collar and float during the test.

In this test the plug of bituminous material becomes warm and fluid and is gradually forced upward and out of the mold until water gains entrance to the saucer and causes it to sink. Latitude is given the test by varying the temperature of the bath. For the more fluid products the test is made at 32°C., for the semi-solid materials, at 50°C., and when the material under examination is somewhat hard, the test may be run at 100°C.

275. Specific Viscosity Determination.—Neither a tentative nor standard method has been published by the American Society for Testing Materials for the Specific Viscosity Determination: but pending standardization by the American Society for Testing Materials, the method contained in *Bulletin 314*, U. S. Department of Agriculture, is recommended as follows:

1. **SPECIFIC VISCOSITY DETERMINATION.**—The viscosity of fluid bituminous road materials may be determined at any suitable temperature by means of the Engler viscosimeter. This apparatus is shown in Fig. 138, and may be described as follows: *a* is a brass vessel for holding the material to be tested, and may be closed by the cover *b*. To the conical bottom of *a*, is fitted a conical outflow tube *c*, exactly 20 mm. long, with a diameter at the top of 2.9 mm. and at the bottom of 2.8 mm. This tube can be closed and opened by the pointed hardwood stopper *d*. Pointed metal projections are placed on the inside of *a* at equal distances from the bottom and serve for measuring the charge of material, which is 240 c.c. The thermometer *e* is used to ascertain the temperature of the material to be tested. The vessel *a* is surrounded by a brass jacket *f*, which holds the material used as a heating bath, either water or cottonseed oil, according to the temperature at which the test is to be made. A tripod *g* serves as a support for the apparatus and also carries a ring burner *h* by means of which the bath is directly heated. The measuring cylinder of 100-c.c. capacity, which is sufficiently accurate for work with road materials, is placed directly under the outflow tube.

As all viscosity determinations should be compared with that of water at 25°C., the apparatus should be previously calibrated as follows: The cup and outlet tube should first be scrupulously cleaned. A piece of soft tissue paper is convenient for cleaning the latter. The stopper is then inserted in the tube and the cup filled with water at 25°C. to the top of the projections. The measuring cylinder should be placed directly under the outflow tube so that the material, upon flowing out,

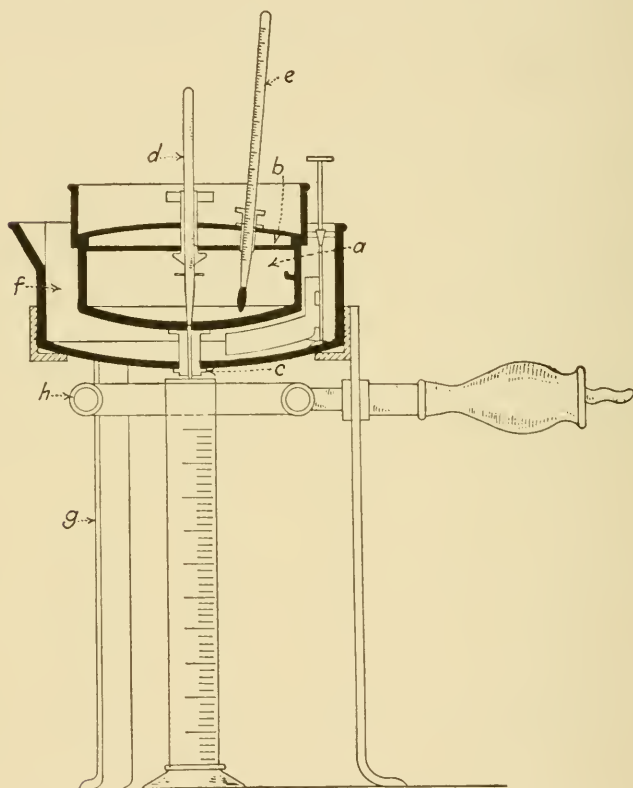


FIG. 138.—Engler viscosimeter.

will not touch the sides, and the stopper may then be removed. The time required both for 50 and 100 c.c. to run out should be ascertained by means of a stop watch and the results so obtained should be checked a number of times. The time required for 50 c.c. of water should be about 11 sec. and for 100 c.c. about 22.8 sec.

Bituminous road materials are tested in the same manner as water and the temperature at which the test is made is controlled by the bath. The material should be brought to the desired temperature and main-

tained there for at least 3 min. before making the test. The results are expressed as specific viscosity compared with water at 25°C., as follows:
Specific viscosity at $a^{\circ}\text{C}$.

$$\frac{\text{seconds for passage of given volume at } a^{\circ}\text{C.}}{\text{seconds for passage of same volume of water at } 25^{\circ}\text{C.}}$$

2. USE OF VISCOSITY DETERMINATION.—For all thin fluid bituminous road materials the specific viscosity is determined at 25°C. with 50 or 100 c.c. Viscous fluid products are run at 40 or 50°C. with 50 c.c. and very viscous products at 100°C. or over with 50 c.c. This test is not always made on the materials above mentioned, but is a useful one when they are required to have a given degree of fluidity at a given temperature.

276. Test for Water.—The presence of water in a bituminous material may usually be detected by the foaming which takes place when it is rapidly heated to above 212°F. Foaming may take place to such an objectionable degree as to interfere with the proper use of the material in construction work. Asphalts are usually free from water since dehydration is an early step in their manufacture. Water, however, often gets into the material through leaky steam pipes used for heating tanks etc., and, therefore, such equipment should be kept in good working shape. Special care must be taken to look for water in tars since in most processes of manufacture water is introduced into the material through the condensers, mechanical scrubbers or other equipment used. Accordingly, it is generally necessary to make sure that satisfactory dehydration has been carried out prior to delivery on the job. The American Society for Testing Materials Tentative Method, D114-21T, is as follows:

1. APPARATUS.—The apparatus shall consist of a copper still, 6 by 3½ in. inside diameter, with an adjustable ring burner to fit the still. The still shall be provided with a connecting tube, a condenser trough, a condenser tube, and a separatory funnel. A thermometer, zero to 250°C., shall be provided. The apparatus shall be set up as shown in Fig. 139.

2. PROCEDURE.—Fifty cubic centimeters of coal-tar naphtha or light oil shall be measured into a 250-c.c. graduated cylinder, and 200 c.c. of the material to be tested shall be added. In the case of petroleum products, petroleum naphtha may be substituted for the coal-tar naphtha. The contents shall be transferred to the copper still and the cylinder shall be washed with 100 to 150 c.c. more of naphtha, and the washings added to the contents of the still. The lid and clamp shall be attached,

using a paper gasket. The condenser trough shall be filled with water. Heat shall be applied by means of the ring burner, and the distillation continued until the vapor temperature has reached 205°C. (401°F.). The distillate shall be collected in the separatory funnel, in which 15 to 20 c.c. of benzol or naphtha have been previously placed in order to effect a clean separation of the water and oil. The reading shall be made after twirling the funnel and allowing the contents to settle for a few minutes. The percentage shall be computed by volume. The naphtha or light oil used shall be tested to determine freedom from water.

3. ACCURACY.—The accuracy obtainable by this method is written 0.1 per cent.

4. PRECAUTIONS.—Every precaution must be taken to insure a representative sample. Bituminous materials containing separated water are especially difficult to sample.

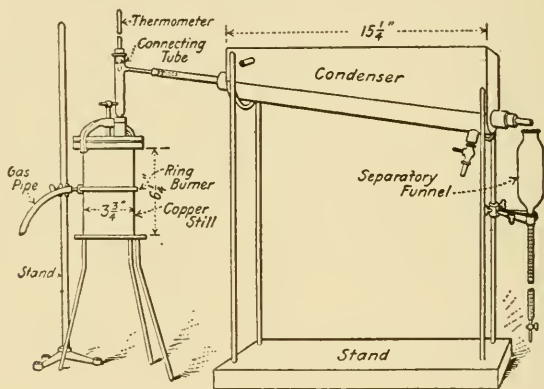


FIG. 139.—Apparatus for the water test.

277. Ring and Ball Softening Point.—In addition to the Test for Water, there are a number of tests based upon the application of heat and they constitute an important group in the investigation and control of bituminous materials. The softening point is easily and quickly determined, for asphalts, by the Ring and Ball method and for tar products, by the Cube in Water method. (The latter method is not applicable to materials having softening points above 77°C. (170.6°F.)). When a single bituminous product is tested by the two methods the melting points obtained are probably within 20° of each other but the relative difference depends upon the nature of the material. The cube method cannot be compared with the Ring and Ball method. The relationship is variable and no factor can be given. The Ring and Ball softening point is widely used for estimating the resis-

tance of asphalt cements to the sun or artificial heat and is generally specified in the case of asphalt fillers for block pavements. The American Society for Testing Materials Standard Method, D36-21, for the Softening Point Test (Ring and Ball method) is as follows:

1. BITUMINOUS MATERIALS OTHER THAN TAR PRODUCTS.—The softening of bituminous materials generally takes place at no definite moment or temperature. As the temperature rises, they gradually and imperceptibly change from a brittle or exceedingly thick and slow

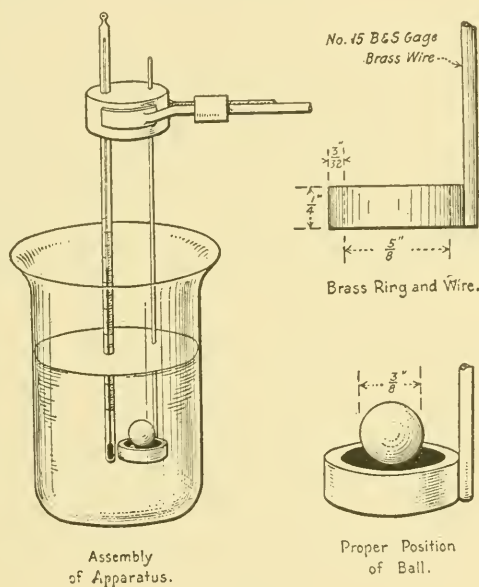


FIG. 140.

flowing material to a softer and less viscous liquid. For this reason the determination of the softening point must be made by a fixed, arbitrary and closely defined method if the results obtained are to be comparable.

2. APPARATUS.—*Ring*.—(a) A brass ring 15.875 mm. ($\frac{5}{8}$ in.) in inside diameter and 6.35 mm. ($\frac{1}{4}$ in.) deep; thickness of wall, 2.38 mm. ($\frac{3}{32}$ in.); permissible variation on inside diameter and thickness of ring, 0.25 mm. (0.01 in.). This ring shall be attached in a convenient manner to a No. 15 B. & S. gauge brass wire (diameter 1.79 mm. = 0.0703 in.) (see Fig. 140).

Ball.—(b) A steel ball 9.53 mm. ($\frac{3}{8}$ in.) in diameter weighing between 3.45 and 3.55 g.

Container.—(c) A glass vessel, capable of being heated, not less than 8.5 cm. (3.34 in.) in diameter and measuring 10.5 cm. (4.13 in.) in depth from the bottom of the flare. (A 600-c.c. beaker, low form, meets this requirement.)

Thermometer.—(d) A thermometer which shall conform to the following specifications:

Total length.....	370-400	mm.	(14.57-15.75 in.)
Diameter.....	6.5-7.5	mm.	(0.256-0.295 in.)
Bulb length.....	Not over 14	mm.	(Not over 0.55 in.)
Bulb diameter.....	4.5-5.5	mm.	(0.177-0.217 in.)

The scale shall be engraved upon the stem of the thermometer, shall be clear cut and distinct, and shall run from zero to 80°C. (32 to 176°F.) in 0.2°C. divisions. It shall commence not less than 7.5 cm. (2.95 in.) above the bottom of the bulb. The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of a suitable quality of glass and be so annealed as not to change its readings under conditions of use. It shall be correct to 0.25°C. (0.45°F.) as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the U. S. Bureau of Standards.

3. PREPARATION OF SAMPLE.—The sample shall be melted and stirred thoroughly, avoiding incorporating air bubbles in the mass, and then poured into the ring so as to leave an excess on cooling. The ring, while being filled, should rest on a brass plate which has been amalgamated to prevent the bituminous material from adhering to it. After cooling, the excess material shall be cut off cleanly with a slightly heated knife.

4. MATERIALS HAVING SOFTENING POINTS 80°C. (176°F.) OR BELOW.
Assembling.—Assemble the apparatus as shown in Fig. 140. Fill the glass vessel to a depth of substantially 8.25 cm. (3.25 in.) with freshly boiled, distilled water at 5°C. (41°F.) Place the ball in the center of the upper surface of the bitumen in the ring and suspend it in the water so that the lower surface of the filled ring is exactly 2.54 cm. (1 in.) above the bottom of the glass vessel and its upper surface is 5.08 cm. (2 in.) below the surface of the water. Allow it to remain in the water for 15 min. before applying heat. Suspend the thermometer so that the bottom of the bulb is level with the bottom of the ring within 0.635 cm. ($\frac{1}{4}$ in.), but not touching, the ring.

Heating.—Apply the heat in such a manner that the temperature of the water is raised 5°C. (9°F.) each minute.

Softening Point.—The temperature recorded by the thermometer at the instant the bituminous material touches the bottom of the glass vessel shall be reported as the softening point.

Rise of Temperature.—The rate of rise of temperature shall be uniform and shall not be averaged over the period of the test. The maximum permissible variation for any minute period after the first three shall be $\pm 0.5^{\circ}\text{C}$. (0.9°F .). All tests in which the rate of rise in temperature exceeds these limits shall be rejected.

5. MODIFICATIONS FOR HARD MATERIALS.—Use the same method as given under (4), except that glycerin shall be used instead of water, and that the thermometer shall conform to the following specifications:

Total length.....	370.0–400.0 mm.	(14.57–15.75 in.)
Diameter of stem.....	6.5– 7.5 mm.	(0.256–0.295 in.)
Bulb length, not over...	14.0 mm.	(0.55 in.)
Bulb diameter.....	4.5– 5.5 mm.	(0.177–0.217 in.)

The graduations shall be from 30 to 160°C . in 0.5°C . and shall be clear cut and distinct. The 30° mark shall be at least 75 mm. above the bottom of the bulb. The length between the 30° mark and 160° mark shall be between 230 and 275 mm.

The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of suitable quality of glass and so annealed as not to change its readings under conditions of use. It shall be correct to 0.25°C . as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the Bureau of Standards.

6. PRECAUTIONS.—The use of freshly boiled, distilled water is essential, as otherwise air bubbles may form on the specimen and affect the accuracy of the results. Rigid adherence to the prescribed rate of heating is absolutely essential in order to secure accuracy of results.

A sheet of paper placed on the bottom of the glass vessel and conveniently weighted will prevent the bituminous material from sticking to the glass vessel, thereby saving considerable time and trouble in cleaning.

7. ACCURACY.—The limit of accuracy of the test is $\pm 0.5^{\circ}\text{C}$. (0.9°F .).

278. Cube in Water Softening Point.—The softening point by the cube in water method is generally specified for pitch fillers for block pavements. The American Society for Testing Materials Tentative Specifications for tar macadam and tar concrete also include, rather than a consistency test, this test for softening point for the heavy tar products used in these types of construction. The American Society for Testing Materials Standard Method, D61–20, for the Softening Point Test (Cube in Water method) is as follows:

1. SOFTENING POINT OF TAR PRODUCTS.—(a) The softening of pitch takes place at no definite moment or temperature. As the tempera-

ture rises, pitch gradually and imperceptibly changes from a brittle or exceedingly thick and slow flowing material to a softer and less viscous liquid. For this reason the determination of the softening point must be made by a fixed, arbitrary and closely defined method if the results obtained are to be comparable.

(b) The methods herein described are not applicable to pitches having a melting point above 77°C . (170.6°F .).

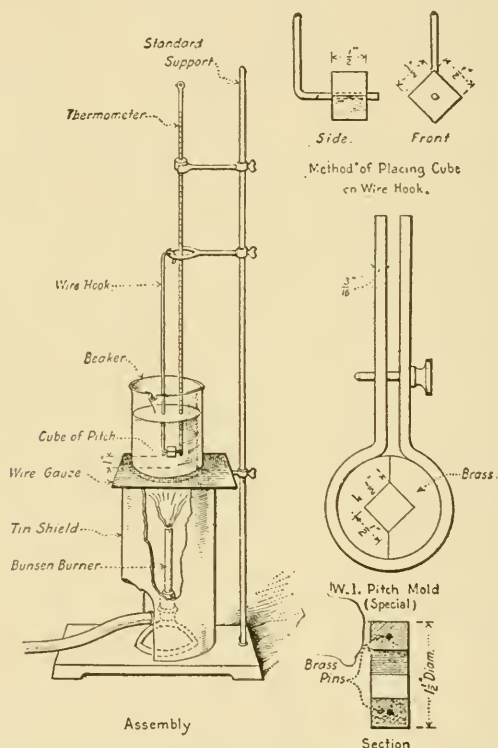


FIG. 141.

(c) For the purpose of shortening the time required for testing, hard pitches having a softening point between 43 and 77°C . (109.4 and 170.6°F .) are cooled at 15.5°C . (60°F .) instead of at 4°C . (39.2°F .) as prescribed for soft pitches.

2. APPARATUS.—*Mold*.—(a) A mold suitable for forming a 12.7-mm. ($\frac{1}{2}$ -in.) cube of pitch. (A recommended type is shown in Fig. 141.)

Hook.—(b) An L-shaped right-angle hook made of No. 12 B. & S. gauge copper wire (diameter 2.05 mm. = 0.0808 in.) the foot of which shall be 2.54 cm. (1 in.) long (see Fig. 3).

Container.—(c) A glass vessel, capable of being heated, not less than 8.5 cm. (3.34 in.) in diameter and measuring 10.5 cm. (4.13 in.) in depth from the bottom of the flare. (A 600-c.c. beaker, Griffin low form, meets this requirement.)

Thermometer.—(d) A thermometer which shall conform to the following specifications:

Total length.....	370–400 mm.	(14.57–15.75 in.)
Diameter.....	6.5–7.5 mm.	(0.256–0.295 in.)
Bulb length.....	Not over 14 mm	(Not over 0.55 in.)
Bulb diameter.....	4.5–5.5 mm.	(0.177–0.217 in.)

The scale shall be engraved upon the stem of the thermometer, shall be clear cut and distinct, and shall run from zero to 80°C. (32 to 176°F.) in 0.2°C. divisions. It shall commence not less than 7.5 cm. (2.95 in.) above the bottom of the bulb. The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of a suitable quality of glass and be so annealed as not to change its readings under conditions of use. It shall be correct to 0.25°C. (0.45°F.) as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the U. S. Bureau of Standards.

3. PREPARATION OF SAMPLE.—The pitch shall be formed into a 12.7-mm. (½-in.) cube, truly shaped and with sharp edges, either by melting and pouring, or softening and pressing, into a mold. In all cases an excess of pitch shall be used and the surplus material shall be cut off cleanly with a slightly heated knife. The harder pitches specified can ordinarily be molded at room temperature, the softer pitches in water at about 4°C. (39.2°F.). If they are melted, they should first be thoroughly stirred, avoiding incorporating air bubbles in the mass, and then poured into the mold so as to leave an excess on cooling. The mold should rest on a brass plate and the surface of the plate and the interior surfaces of the mold should be amalgamated to prevent the pitch from adhering to them.

4. PITCHES HAVING SOFTENING POINTS BETWEEN 43 AND 77°C. (109.4 AND 170.6°F.).—*Assembling.*—Assemble the apparatus as shown in Fig. 141. Fill the glass vessel to a depth of substantially 9.5 cm. (3.75 in.) with freshly boiled, distilled water at 15.5°C. (60°F.). Place the cube of pitch on the wire as shown in Fig. 1, and suspend it in the water so that its lower edge is exactly 2.54 cm. (1 in.) above the bottom of the glass vessel and its upper edge is 5.08 cm. (2 in.) below the surface of the water. Allow it to remain in the water for 15 min. before applying heat. Suspend the thermometer so that the bottom of the bulb is level with the bottom edge of the cube of pitch and within 0.635 cm. (¼ in.) but not touching, the cube.

Heating.—Apply the heat in such a manner that the temperature of the water is raised 5°C. (9°F.) each minute.

Softening Point.—The temperature recorded by the thermometer at the instant the pitch touches the bottom of the glass vessel shall be reported as the softening point.

Permissible Variation in Rise of Temperature.—The rate of rise of temperature shall be uniform and shall not be averaged over the period of the test. The maximum permissible variation for any minute period after the first three shall be $\pm 0.5^{\circ}\text{C}$. (0.9°F .). All tests in which the rate of rise in temperature exceeds these limits shall be rejected.

5. PITCHES HAVING SOFTENING POINTS BELOW 43°C. (109.4°F.).—Use the same method as given under (4), except that the water when placed in the glass vessel shall be at a temperature of 4°C. (39.2°F.). The cube shall be allowed to remain 15 min. in this water before applying the heat.

6. PRECAUTIONS.—The use of freshly distilled water is essential, as otherwise air bubbles may form on the cube and retard its sinking. Rigid adherence to the prescribed rate of heating is absolutely essential in order to secure accuracy of results.

A sheet of paper placed on the bottom of the glass vessel and conveniently weighted will prevent the pitch from sticking to the glass vessel, thereby saving considerable time and trouble in cleaning.

7. ACCURACY.—The limit of accuracy of the test is $\pm 0.5^{\circ}\text{C}$. (0.9°F .).

279. Test for Loss on Heating.—The object of the Test for Loss on Heating is to determine the loss when the material is subjected to a temperature of 163°C. for 5 hr., and also to ascertain any changes in the character of the material due to such heating. Though there are no actual data in support of the assumption, it is often regarded as an accelerated test, giving an indication of what will take place upon exposure in a pavement for a long time. The test is generally limited to asphalts since for tars and pitches the matter is covered by the Distillation Test next to be described. The American Society for Testing Materials Standard Method, D6-20, is as follows:

1. LOSS ON HEATING OF OIL AND ASPHALTIC COMPOUNDS.—This test is used to determine the loss in weight (exclusive of water) of oil and asphaltic compounds when heated as hereinafter prescribed. The material under examination must therefore first be tested for water and if water is found to be present, it must be removed by suitable methods of dehydration before the material is subjected to the loss on heating test; or another sample obtained which is free from water.

2. OVEN.—The oven may be either circular or rectangular in form and may be heated by either gas or electricity. Its interior dimensions shall be as follows: Height, not less than 40.64 cm. (16 in.); width and depth or diameter, at least 4.08 cm. (2 in.) greater than the diameter of the revolving shelf.

It shall be well ventilated and shall be fitted with a window in the upper half of the door, so placed and of sufficient size to permit the accurate reading of the thermometer without opening the door. It shall also be provided with a perforated circular shelf preferably of approximately 24.8 cm. (9.75 in.) in diameter. This shelf shall be placed in the center of the oven and shall be suspended by a vertical shaft and provided with mechanical means for rotating it at the rate of 5 to 6 r.p.m. It shall be provided with recesses equidistant from the central shaft in which the tins containing the samples are to be placed.

3. THERMOMETER.—The thermometer shall be between 12.7 cm. (5 in.) and 15.24 cm. (6 in.) in length and the mercury bulb shall be from 10 to 15 mm. (0.39 to 0.59 in.) in length. The scale shall be engraved on the stem, shall be clear cut and distinct, and shall run from 150 to 175°C. (302 to 347°F.) in 1°C. divisions and shall commence substantially 3.81 cm. (1½ in.) above the top of the bulb. Every fifth graduation shall be larger than the intermediate ones and shall be numbered. The degrees shall be substantially 3.17 mm. (⅓ in.) apart. The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of a suitable quality of glass and be so annealed as to not change its readings under conditions of use. It shall be correct to 0.25°C. (0.45°F.) as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the U. S. Bureau of Standards.

4. CONTAINER.—The container in which the sample is to be tested shall be of tin, cylindrical in shape, and shall have a flat bottom. Its inside dimensions shall be substantially as follows: Diameter, 55 mm. (2.17 in.); depth, 35 mm. (1.38 in.). A 3-oz. Gill style ointment box, deep pattens, fulfills these requirements.

5. PREPARATION OF SAMPLE.—The sample as received shall be thoroughly stirred and agitated, warming, if necessary, to insure complete mixture before the portion for analysis is removed.

6. PROCEDURE.—Weigh 50 g. of the water-free material to be tested into a tarred container conforming to the requirements of Sec. 4. Bring the oven to a temperature of 163°C. (325°F.), and place the tin box containing the sample in one of the recesses of the revolving shelf. The thermometer shall be immersed for the depth of its bulb in a separate 50-g. sample of the material under test, placed in a similar container, and shall be conveniently suspended from the vertical shaft. This sample shall rest in one of the recesses upon the same shelf and revolve

with the sample or samples under test. Then close the oven and rotate the shelf 5 to 6 r.p.m. during the entire test. Maintain the temperature at 163°C. (325°F.) for 5 hr., then remove the sample from the oven, cool and weigh, and calculate the loss due to volatilization.

7. PERMISSIBLE VARIATION IN TEMPERATURE.—During the 5-hr. period the temperature shall not vary more than 1°C. All tests showing a greater variation in temperature shall be rejected.

8. PRECAUTIONS.—Under ordinary circumstances a number of samples having about the same degree of volatility may be tested at the same time. Samples varying greatly in volatility should be tested separately. Where extreme accuracy is required not more than one material should be tested at one time and duplicate samples of it should be placed simultaneously in the oven. Such duplicates shall check within the limits of accuracy given above. Results obtained on samples showing evidences of foaming during the test shall be rejected.

9. ACCURACY.—Up to 5 per cent loss in weight the results obtained may be considered as correct within 0.5. Above 5 per cent loss in weight the numerical limit of error increases 0.01 for every 0.5 per cent increase in loss by volatilization as follows:

VOLATILIZATION Loss, PER CENT	NUMERICAL CORRECTION	TRUE VOLATILIZATION Loss, PER CENT
5.0	± 0.50	4.50 to 5.50
5.5	0.51	4.91 to 6.01
6.0	0.52	5.48 to 6.52
10.0	0.60	9.40 to 10.60
15.0	0.70	14.30 to 15.70
25.0	0.90	24.10 to 25.90
40.0	1.20	38.80 to 41.20

NOTE.—If additional periods of heating are desired, it is recommended that they be made in successive increments of 5 hr. each.

When the penetration of the sample after heating is required, melt the residue in the container at the lowest possible temperature and thoroughly mix by stirring, taking care to avoid incorporating air bubbles in the mass. Then bring it to the standard temperature and test as prescribed under the directions for the Standard Method of Test for Penetration of Bituminous Materials (Serial Designation: D5) of the American Society for Testing Materials.

280. Distillation Test.—The distillation test is generally applied to tar products as an equivalent of the Test for Loss on Heating and, further, as a means of identifying the different kinds of tar products. The American Society for Testing Materials Standard Method, D20-18, is as follows:

1. **SAMPLING.**—The sample as received shall be thoroughly stirred and agitated, warming, if necessary, to insure a complete mixture before the portion for analysis is removed.

2. **DEHYDRATION.**—If the presence of water is suspected or known, the material shall be dehydrated before distillation. About 500 c.c. of the material are placed in an 800-c.c. copper still provided with a distilling head connected with a water-cooled condenser. A ring burner is used, starting with a small flame at the top of the still, and gradually lowering it, if necessary, until all the water has been driven off. The distillate is collected in a 200-c.c. separatory funnel with the tube cut off close to the stopcock. When all the water has been driven over and the distillate has settled out, the water is drawn off and the oils returned to the residue in the still. The contents of the still shall have cooled to below 100°C. before the oils are returned, and they shall be well stirred and mixed with the residue.

3. **APPARATUS.**—The apparatus shall consist of the following standard parts:

(a) *Flask.*—The distillation flask shall be a 250-c.c. Engler distilling flask, having the following dimensions:

Diameter of bulb.....	8.0 cm.
Length of neck.....	15.0 cm.
Diameter of neck.....	1.7 cm.
Surface of material to lower side of tubulature..	11.0 cm.
Length of tubulature.....	15.0 cm.
Diameter of tubulature.....	0.9 cm.
Angle of tubulature.....	75.0 deg.

A variation of 3 per cent from the above measurements will be allowed.

(b) *Thermometer.*—The thermometer shall conform to the following requirements:

It shall be made of thermometric glass of a quality equivalent to suitable grades of Jena or Corning make. It shall be thoroughly annealed. It shall be filled above the mercury with inert gas which will not act chemically on or contaminate the mercury. The pressure of the gas shall be sufficient to prevent separation of the mercury column at all temperatures of the scale. There shall be a reservoir above the final graduation large enough so that the pressure will not become excessive at the highest temperature. The thermometer shall be finished at the top with a small glass ring or button suitable for attaching a tag. Each thermometer shall have for identification the maker's name, a serial number, and the letters "A.S.T.M. Distillation."

The thermometer shall be graduated from zero to 400°C. at intervals of 1°C. Every fifth graduation shall be longer than the intermediate

ones, and every tenth graduation beginning at zero shall be numbered. The graduation marks and numbers shall be clear-cut and distinct.

The thermometer shall conform to the following dimensions:

Total length, maximum....	385 mm.
Diameter of stem.....	7 mm.; permissible variation, 0.5 mm.
Diameter of bulb, minimum	5 mm.; and shall not exceed diameter of stem.
Length of bulb.....	12.5 mm.; permissible variation, 2.5 mm.
Distance from zero to bottom of bulb.....	30 mm.; permissible variation, 5.0 mm.
Distance from zero to 400°..	295 mm.; permissible variation, 10.0 mm.

The accuracy of the thermometer when delivered to the purchaser shall be such that when tested at full immersion the maximum error from zero to 200°C. shall not exceed the following:

From zero to 200°C.....	0.5°C.
From 200 to 300°C.....	1.0°C.
From 300 to 375°C.....	1.5°C.

The sensitiveness of the thermometer shall be such that when cooled to a temperature of 74°C. below the boiling point of water at the barometric pressure, at the time of test, and plunged into free flow of steam, the meniscus shall pass the point 10°C. below the boiling point of water in not more than 6 sec.

The thermometer shall be set up as for the distillation test, using water, naphthalene and benzophenone as distilling liquids. The correctness of the thermometer shall be checked at zero and 100°C. after each third distillation until seasoned.

(c) *Condenser*.—The condenser tube shall have the following dimensions:

Adapter.....	70 mm.
Length of straight tube.....	185 mm.
Width of tube.....	12 to 15 mm.
Width of adapter end of tube.....	20 to 25 mm.

(d) *Stands*.—Two iron stands shall be provided, one with a universal clamp for holding the condenser, and one with a light grip arm with a cork-lined clamp for holding the flask.

(e) *Burner and Shield*.—A Bunsen burner shall be provided, with a tin shield 20 cm. long by 9 cm. in diameter. The shield shall have a small hole for observing the flame.

(f) *Cylinders*.—The cylinders used in collecting the distillate shall have a capacity of 25 c.c., and shall be graduated in 0.1 c.c.

4. **SETTING UP THE APPARATUS**.—The apparatus shall be set up as shown in Fig. 142, the thermometer being placed so that the top of the bulb is opposite the middle of the tubulature. All connections should be tight.

5. **PROCEDURE**.—One hundred cubic centimeters of the dehydrated material to be tested shall be placed in a tared flask and weighed. After adjusting the thermometer, shield, condenser, etc., the distillation is commenced, the rate being so regulated that 1 c.c. passes over every minute. The receiver is changed as the mercury column just passes the fractionating point.

The following fractions should be reported :

Start of distillation to 110°C.

110 to 170°C.

70 to 235°C.

235 to 270°C.

270 to 300°C.

Residue.

To determine the amount of residue, the flask is weighed again when distillation is complete. During the distillation the condenser tube shall be warmed when necessary to prevent the deposition of any sublimate. The percentages of fractions should be reported both by weight and by volume.

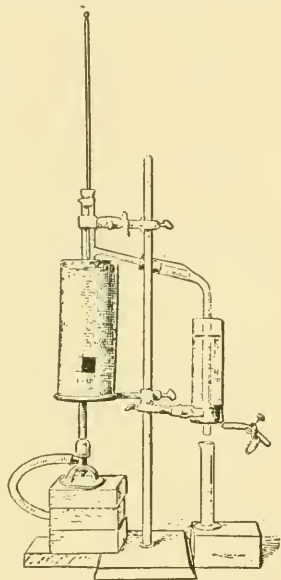


FIG. 142.—Apparatus for distillation test.

281. Flash Test.—The flash test is a quick means of determining whether or not there are volatile constituents in a product. Thus materials cut back with light distillates necessarily show a lower flash than do straight residuals of the same consistency. Under some conditions the temperature at which a material flashes may be considered as a danger point and, therefore, the test serves as a criterion of the fire hazard. The American Society for Testing Materials Tentative Method, D92-21T, is as follows:

1. **SCOPE**.—The open-cup flash and fire test on all products except fuel oils and those having an open-cup flash below 175°F. shall be determined in the Cleveland Open Cup.

2. FLASH CUP.—The flash cup proper shall be made of brass and shall have the following dimensions:

	INCHES		CENTIMETERS	
	DIMEN- SIONS	TOLER- ANCES	DIMEN- SIONS	TOLER- ANCES
Inside diameter.....	2½	± ⅛	6.350	± 0.079
Outside diameter.....	2 11/16	⅛	6.826	0.079
Inside height.....	1 5/16	⅛	3.334	0.079
Thickness of bottom.....	⅛	1/64	0.318	0.040
Depth of filling mark below top of cup.....	3/8	1/64	0.953	0.040

The cup shall be heated by contact with a metal plate ¼ in. (0.635 cm.) thick and 6 in. (15.24 cm.) wide. (The plate may be of any suitable metal and may be either circular or square.) In the center of the plate there shall be a plane depression ⅛ in. (0.079 cm.) deep and of diameter just sufficient to fit the cup. The plate shall be covered with a sheet of hard asbestos board ¼ in. (0.635 cm.) thick and of the same shape as the metal plate. There shall be cut in the center of the asbestos board a circular hole just fitting the cup. The metal plate may be heated in any convenient manner. The use of a gas burner, electric heater, or alcohol lamp is permitted. If a flame heater is used it may be protected from drafts or excessive radiation by any suitable type of shield that does not project above the level of the upper surface of the asbestos board.

3. THERMOMETER.—The thermometer shall conform to the following specifications.

<i>Type:</i>	Etched stem glass.
<i>Total length:</i>	305 mm.
<i>Stem:</i>	Plain front, enamel back, suitable thermometer tubing. Diameter 6 to 7 mm.
<i>Bulb:</i>	Corning normal, Jena 16, III, or equally suitable thermometric glass. Length, 13 mm. maximum. Diameter, not greater than stem.
<i>Actuating Liquid:</i>	Mercury.
<i>Range:</i>	+20 to +760°F
<i>Immersion:</i>	One inch. The words "1-in. immersion" shall be etched on the stem and also a line around the stem to indicate the depth of immersion.
<i>Distance to 20° line from bottom of bulb:</i>	40 to 50 mm.
<i>Distance to 760° line from top of stem:</i>	30 to 45 mm.

<i>Filled:</i>	Nitrogen gas.
<i>Top finish:</i>	Red glass ring.
<i>Graduation:</i>	All lines, figures and letters clear cut and distinct. Scale graduated in 5° divisions. Scale numbered every 20°, the first and each succeeding 10°F. line to be longer than the others.
<i>Special marking:</i>	"A.S.T.M. Open Flash," serial number and manufacturer's name or trade mark etched on stem.
<i>Accuracy:</i>	Error at any point on scale shall not exceed one-half smallest scale division up to 700°F.
<i>Test for permanency of range:</i>	After being subjected to a temperature of 700°F. for 24 hr. the accuracy shall be within the limit specified.
<i>Points to be tested for certification:</i>	32, 212, 400, 700°F.

4. PROCEDURE.—(a) The thermometer shall be suspended or held in a vertical position by any suitable device. The bottom of the bulb shall be $\frac{1}{4}$ in. (0.635 cm.)¹ from the bottom of the cup, and above a point half way between the center and back of the cup.

(b) The cup shall be filled with the oil to be tested in such a manner that the top of the meniscus is exactly at the filling line at room temperature. The surface of the oil shall be free from bubbles. There shall be no oil above the filling line or on the outside of the apparatus.

(c) The test flame shall be approximately $\frac{5}{32}$ in. (0.397 cm.) in diameter.

Note.—For purposes of comparison it is recommended that a bead of suitable light colored material be mounted in a convenient position so that the size of the test flame can be determined. The device for applying the flame may be of any suitable type but it is suggested that the tip be approximately $\frac{1}{16}$ in. (0.159 cm.) in diameter at the end and that the orifice be $\frac{1}{32}$ in. (0.079 cm.) in diameter. If the device for operating the test flame be mounted in such a manner as to permit automatic duplication of the sweep of the test flame the radius of swing shall be not less than 6 in.

(d) The test flame shall be applied as the temperature read on the thermometer reaches each successive 5°F. mark. The flame shall pass in a straight line (or on the circumference of a circle having a radius of at least 6 in.) across the center of the cup and at right angles to the diameter passing through the thermometer. The test flame shall, while passing across the surface of the oil, be in the plane of the upper edge of the cup. The time for the passage of the test flame across the cup shall be approximately one second.

¹ The immersion line engraved on the thermometer stem will be $\frac{1}{16}$ in. (0.159 cm.) below the level of the rim of the cup.

(e) The rate of heating of the oil shall be such that the temperature read on the thermometer increases not less than 9 nor more than 11°F. per minute.

5. **FLASH POINT.**—The flash point shall be taken as the temperature read on the thermometer when a flash appears at any point on the surface of the oil. The true flash must not be confused with a bluish halo that sometimes surrounds the test flame.

6. **FIRE POINT.**—After determining the flash point the heating shall be continued at the specified rate, and application of the test flame shall be made at the specified intervals until the oil ignites and continues to burn for a period of at least 5 sec. The temperature read when this occurs shall be taken as the fire point.

7. **PRECAUTIONS.**—The flash point and fire point tests shall be made in a room or compartment free from air drafts. The operator shall avoid breathing over the surface of the oil. It is desirable that the room or compartment be darkened sufficiently so that the flash may be readily discernible.

282. Test for Soluble Bitumen.—The percentage of bitumen soluble in carbon disulfide is useful for purposes of identification; also as a criterion of purity and intrinsic value of the material. Plastic bitumen is the binding agent in both asphalts and tar products. Relatively more asphalt cement has to be used with asphalts containing large quantities of inert material, than when cements are used that are almost pure bitumen. This is also true in the case of tar products when organic matter insoluble, commonly known and reported as “free carbon,” is present. That the percentage of soluble bitumen is useful as a criterion of value may be open to dispute on the basis that the test for solubility does not reveal anything as to the quality of the bitumen nor anything as to the nature of the insoluble material. Finely divided mineral matter in a native asphalt may perhaps be of more worth than any material that could be substituted therefore, and the insoluble matter in tar products may perhaps add to the binding qualities of those materials. The highway man is interested in knowing how much of a given product must be bought to obtain certain results. In addition to the Test for Soluble Bitumen, certain physical tests are necessary and these are described in Chap. XVI, “Design of Bituminous Mixtures.”

As stated in the list of definitions, bitumen may be fluid, as, for instance, the volatile distillates used in cutting back or liquefying tars and asphalts in order that they may be used without heating. These volatile agents are, of course, carried out as

bitumen with the carbon disulfide when the test for soluble bitumen is made. The American Society for Testing Materials Standard method for the test, D4-11, is as follows:

A.S.T.M. STANDARD METHOD

1. DRYING THE SAMPLE AND PREPARING IT FOR ANALYSIS.—It was decided, owing to the great variety of conditions met with in bituminous compounds, that it is impossible to specify any one method of drying that would be satisfactory in every case. It is therefore supposed that the material for analysis has been previously dried either in the laboratory or in the process of refining or manufacture, and that water, if present, exists only as moisture in the hygroscopic form.

The material to be analyzed, if hard and brittle, is ground and spread in a thin layer in a suitable dish (iron or nickel will answer every purpose) and kept at a temperature of 125°C. for 1 hr. In the case of paving mixtures and road materials, where it is not desirable to crush the rock or sand grains, a lump may be placed in the drying oven until it is thoroughly heated through, when it can be crushed down into a thin layer and dried as above. If the material under examination contains any hydrocarbons at all volatile at this temperature, it will of course be necessary to resort to other means of drying. Tar or oils may be dehydrated by distillation and the water-free distillate returned to the residue and thoroughly incorporated with it.

2. ANALYSIS OF SAMPLE.—After drying, from 2 to 15 g. (as may be necessary to insure the presence of 1 to 2 g. of pure bitumen) is weighed into a 150-c.c. tarred Erlenmeyer flask, and treated with 100 c.c. of carbon disulfide. The flask is then loosely corked and shaken from time to time until all large particles of the material have been broken up. It is then set aside for 48 hr. to settle. The solution is decanted into a similar flask that has been previously weighed. As much of the solvent is poured off as possible without disturbing the residue. The contents of the first flask are again treated with fresh carbon disulfide, shaken as before, and then put away with the second flask for 48 hr. to settle.

The liquid in the second flask is then carefully decanted upon a weighed Gooch crucible, 3.2 cm. in diameter at the bottom, fitted with an asbestos filter, and the contents of the first flask are similarly treated. The asbestos filter is made of ignited long-fiber amphibole, packed in the bottom of a Gooch crucible to the depth of not over $\frac{1}{8}$ in. In filtering no vacuum is to be used and the temperature is to be kept between 20 and 25°C. After passing the liquid contents of both flasks through the filter, the residue on the filter is thoroughly washed and the residues remaining in them are shaken with more fresh carbon disulfide and allowed to settle for 24 hr., or until it is seen that a good subsidence has taken place. The solvent in both flasks is then again decanted

through the filter and the residues remaining in them are washed until the washings are practically colorless. All washings are to be passed through the Gooch crucible.

The crucible and both flasks are then dried at 125°C. and weighed. The filtrate containing the bitumen is evaporated, the bituminous residue burned, and the weight of the ash thus obtained added to that of the residue in the two flasks and the crucible. The sum of these weights deducted from the weight of substance taken gives the weight of soluble bitumen.

The A.S.T.M. method is generally recommended for use only in case of a dispute as there are other more expeditious methods satisfactory for general use. The method given in *Bulletin 314*, U. S. Department of Agriculture, is as follows:

U. S. DEPARTMENT OF AGRICULTURE METHOD

1. APPARATUS.—This test consists in dissolving the bitumen in carbon disulfide and recovering any insoluble matter by filtering the solution through an asbestos felt. The form of Gooch crucible best adapted for the determination is 4.4 cm. wide at the top, tapering to 3.6 cm. at the bottom, and is 2.5 cm. deep.

For preparing the felt the necessary apparatus is arranged as shown in Fig. 143, in which *a* is the filtering flask, *b* a rubber stopper, *c* the filter tube, and *d* a section of rubber tubing which tightly clasps the Gooch crucible *e*. The asbestos is cut with scissors into pieces not exceeding 1 cm. in length, after which it is shaken up with just sufficient water to pour easily. The crucible is filled with the suspended asbestos, which is allowed to settle for a few moments. A light suction is then applied to draw off all the water and leave a firm mat of asbestos in the crucible. More of the suspended material is added, and the operation is repeated until the felt is so dense that it scarcely transmits light when held so that the bottom of the crucible is between the eye and the source of light. The felt should then be washed several times with water, and drawn firmly against the bottom of the crucible by an increased suction. The crucible is removed to a drying oven for a few minutes, after which it is ignited at red heat over a bunsen burner, cooled in a desiccator and weighed.

2. METHOD.—From 1 to 2 g. of bitumen or about 10 g. of an asphalt topping or rock asphalt is now placed in the Erlenmeyer flask, which has been previously weighed, and the accurate weight of the sample is obtained. One hundred cubic centimeters of chemically pure carbon disulfide is poured into the flask in small portions, with continual agitation, until all lumps disappear and nothing adheres to the bottom. The flask is then corked and set aside for 15 min.

After being weighed, the Gooch crucible containing the felt is set up over the dry pressure flask, as shown in Fig. 143, and the solution of bitumen in carbon disulfide is decanted through the felt without suction by gradually tilting the flask, with care not to stir up any precipitate that may have settled out. At the first sign of any sediment coming out, the decantation is stopped and the filter allowed to drain. A small amount of carbon disulfide is then washed down the sides of the flask, after which the precipitate is brought upon the felt

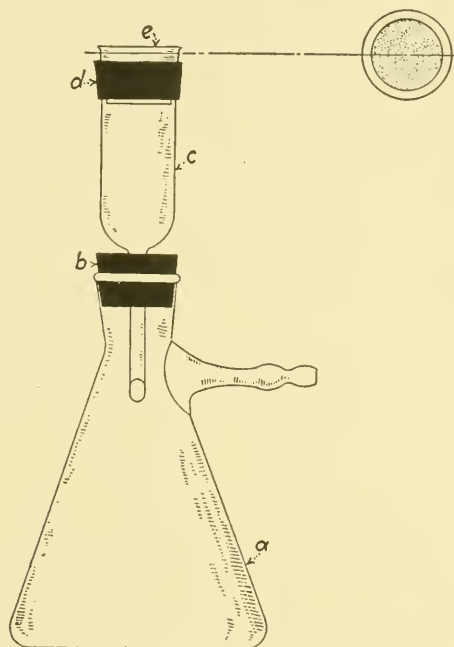


FIG. 143.—Apparatus for determining soluble bitumen.

and the flask scrubbed, if necessary, with a feather or "policeman," to remove all adhering material. The contents of the crucible are washed with carbon disulfide, until the washings run colorless. Suction is then applied until there is practically no odor of carbon disulfide in the crucible, after which the outside of the crucible is cleaned with a cloth moistened with a small amount of the solvent. The crucible and contents are dried in the hot-air oven at $100^{\circ}\text{C}.$ for about 20 min., cooled in a desiccator, and weighed. If any appreciable amount of insoluble matter adheres to the flask, it should also be dried and weighed, and any increase over the original weight of the flask should be added to the weight of the insoluble matter in the crucible. The total weight of insoluble material may include both organic and mineral matter. The former,

if present, is burned off by ignition at a red heat until no incandescent particles remain, thus leaving the mineral matter or ash, which can be weighed on cooling. The difference between the total weight of material insoluble in carbon disulfide and the weight of substance taken equals the total bitumen, and the percentage weights are calculated and reported as total bitumen, and organic and inorganic matter insoluble, on the basis of the weight of material taken for analysis.

3. LIMITATIONS.—This method is quite satisfactory for straight oil and tar products, but where certain natural asphalts are present it will be found practically impossible to retain all of the finely divided mineral matter on an asbestos felt. It is, therefore, generally more accurate to obtain the result for total mineral matter by direct ignition of a 1-g. sample in a platinum crucible or to use the result for ash obtained in the fixed carbon test. The total bitumen is then determined by deducting from 100 per cent the sum of the percentages of total mineral matter and organic matter insoluble. If the presence of a carbonate mineral is suspected, the percentage of mineral matter may be most accurately obtained by treating the ash from the fixed carbon determination with a few drops of ammonium carbonate solution, drying at 100°C., then heating for a few minutes at a dull-red heat, cooling and weighing again.

When difficulty in filtering is experienced—for instance, when Trinidad asphalt is present in any amount—a period of longer subsidence than 15 min. is necessary, and the method proposed by the Standard Test of the American Society for Testing Materials is recommended.

CENTRIFUGAL METHOD

For Trinidad and other cements carrying much mineral matter, and also for pavement mixtures, especially when the aggregate

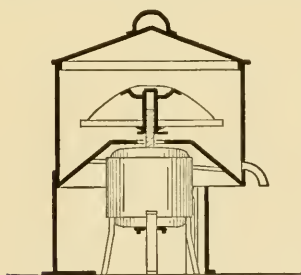


FIG. 144A.—Centrifugal extractor.

contains large particles, the bitumen can be quickly determined by centrifugal machines. The accuracy of the centrifuge method is sufficient for ordinary purposes. It is particularly useful for the purpose of recovering the aggregate for subsequent examination. The following is quoted from *Bulletin 949*, 1921, U. S. Department of Agriculture:

1. APPARATUS.—The extractor shown in Fig. 144A, was designed upon lines suggested by an examination of machines in use by A. E. Schutte and C. N. Forrest.¹ It consists of a $\frac{1}{2}$ -hp., 1,100-r.p.m.

¹Any extractor of similar design may be used.

vertical-shaft electric motor *a* with the shaft projecting into the cylindrical copper box *b*, the bottom of which is so inclined as to drain the spout *c*. A $\frac{3}{16}$ -in. circular brass plate $9\frac{1}{2}$ in. in diameter is shown in *d*, and upon this rests the sheet-iron bowl *e*, which is $8\frac{1}{2}$ in. in diameter by $2\frac{5}{16}$ in. high, and has a 2-in. circular hole in the top. Fastened to the inner side of the bowl is the brass cup *f*, having a circle of $\frac{1}{8}$ -in. holes for the admission of the solvent, and terminating in the hollow axle, which fits snugly through a hole at the center of the brass plate. The bowl may be drawn firmly against a felt-paper ring *g*, $\frac{3}{4}$ in. wide, by means of the $2\frac{1}{2}$ -in. milled nut *h*, for which the hollow axle is threaded for a distance of $\frac{3}{4}$ in. directly below the upper surface of the plate. The axle fits snugly over the shaft of the motor, to which it is locked by a slot and crosspin, *i*.

2. EXTRACTION.—The aggregate is prepared for analysis by heating it in an enamel-ware pan on the hot plate until it is sufficiently soft to be thoroughly disintegrated by means of a large spoon. Care must be taken, however, that the individual particles are not crushed. If a section of pavement is under examination, a piece weighing somewhat over 1 kg. may be cut off with hammer and chisel. The disintegrated aggregate is then allowed to cool, after which a sufficient amount is taken to yield on extraction from 50 to 60 g. of bitumen. It is placed in the iron bowl and a ring $\frac{3}{4}$ in. wide, cut from the felt paper, is fitted on the rim, after which the brass plate is placed in position and drawn down tightly by means of the milled nut. If the bitumen is to be recovered and examined, the felt ring should be previously treated in the empty extractor with a couple of charges of carbon disulfide in order to remove any small amount of grease or resin that may be present, although a proper grade of felt should be practically free from such products. The bowl is now placed on the motor shaft and the slot and pin are carefully locked. An empty bottle is placed under the spout and 150 c.c. of carbon disulfide (carbon tetrachloride, benzole, or chloroform may also be used as solvents) is poured into the bowl through the small holes. The cover is put on the copper box and, after allowing the material to digest for a few minutes, the motor is started slowly at first in order to permit the aggregate to distribute uniformly. The speed should then be increased sufficiently by means of the regulator to cause the dissolved bitumen to flow from the spout in a thin stream. When the first charge has drained, the motor is stopped and a fresh portion of disulfide is added. This operation is repeated from four to six times with 150 c.c. of disulfide. With a little experience the operator can soon gauge exactly what treatment is necessary for any given material. When the last addition of solvent has drained off, the bowl is removed and placed with the brass plate uppermost on a sheet of manila paper. The brass plate and felt ring are carefully laid aside on the paper and, when the aggregate is thoroughly dry, it can be brushed on a pan of the

rough balance and weighed. The difference between this weight and the original weight taken shows the amount of bitumen extracted. The aggregate may then be tested as occasion requires.

3. RECOVERY OF BITUMEN.—When it is desired to recover and examine the bitumen, the apparatus shown in Fig. 144*B*, will be found convenient and fairly safe for the distillation and recovery of such inflammable solvents as carbon disulfide. In the laboratory of the Bureau of Public Roads this apparatus is arranged so that the glass tubing passes through a stone partition between two sections of a small hood, thus keeping the distilling and receiving apparatus entirely separated.

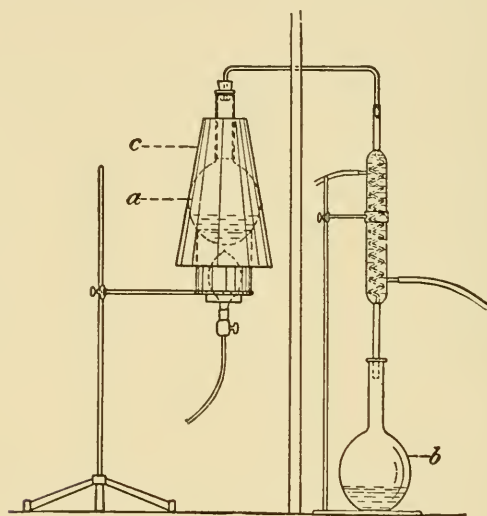


FIG. 144*B*.—Bitumen recovery apparatus.

The solution of bitumen should be allowed to stand overnight in order to permit the settling of any fine mineral matter that is sometimes carried through the felt ring in the extractor. The solution is then decanted into the flask *a*, and the solvent is driven off by means of heat from an incandescent lamp until the residue is of a thick sirupy consistency. Meanwhile the solvent is condensed and recovered in the flask *b*. The residue is poured into an 11-cm. porcelain evaporating dish and evaporated on a steam bath. The most scrupulous care must be taken at all times that no flames are in its immediate vicinity. Evaporation is carried on at a gentle heat, with continual stirring, until foaming practically ceases. It is advisable to have a large watch glass at hand to smother the flames quickly should the material ignite. As the foaming subsides, the heat of the steam bath may be gradually raised, and evaporation is continued until the bubbles beaten or stirred

to the surface of the bitumen fail to give a blue flame or odor of sulphur dioxide when ignited by a small gas jet. The dish of bitumen should then be set in a hot-air oven maintained at 105°C. for about 1 hr., after which it is allowed to cool. Its general character is noted and any tests for bitumens that are necessary are then made upon it.

4. **ASH CORRECTION.**—The difference between the final aggregate and the original amount taken gives the amount of bitumen extracted, which is subject to correction, dependent on the amount of ash determined from the washings.

Ash correction shall be made in the following manner: The total solution of bitumen, well stirred, is rapidly measured and an aliquot portion taken, usually 100 c.c., and poured into a previously weighed suitable flat-bottom dish, preferably quartz. The solvent is evaporated over a very low flame and the residual coke is then ignited with a burner capable of furnishing high temperature, such as a Meker. (Caution: When an inflammable solvent is used evaporation should be conducted on a steam bath and care should be taken that no flames are in the immediate vicinity.) The dish and contents are then cooled in a desiccator and the percentage of ash calculated.

283. Bitumen Soluble in Carbon Tetrachloride.—The test for determining the proportion of bitumen soluble in carbon tetrachloride, as provided for in *Bulletin 314*, U. S. Department of Agriculture, is conducted in exactly the same manner as heretofore described for the Department's method of testing for soluble bitumen, using 100 c.c. of chemically pure carbon tetrachloride in place of carbon disulfide. The percentage of bitumen soluble in carbon tetrachloride is reported upon the basis of total bitumen taken as 100. The bitumen insoluble in carbon tetrachloride, but soluble in carbon disulfide, is commonly known as "Carbenes."

The carbon tetrachloride test is made on petroleums, asphalts, and other solid native bitumens and their products, for the purpose of identification, or when there is any reason to suspect that the material under examination has been injured by overheating during the process of manufacture. In the American Society for Testing Materials 1922 Tentative Specifications, in order to cover both lake and petroleum asphalts the carbon tetrachloride test is included rather than the carbon disulfide test. The latter, however, has to be made in order to determine the carbon tetrachloride solubility and therefore the bitumen soluble in carbon disulfide is always available as a matter of record.

284. Test for Ductility.—A certain degree of ductility indicates the length in centimeters that a small briquette of the material will stretch under given conditions without rupture. A well fluxed Trinidad may have a ductility as low as 35, though generally above 40. Most blown asphalts usually have much less

than 35, breaking without pulling out to a thread, while straight residual asphalts pull out to a long thread very often giving a ductility considerably above 100.

The Ductility Test may sometimes aid differentiation between blown petroleum asphalts, native asphalts and residual ones, but as a measure of the worth of a bituminous material for paving purposes, especially for ductilities above 15 and below 150, it is of minor value. The American Society for Testing Materials Tentative Method, D113-22T, is as follows:

1. DEFINITION.—The ductility of an asphalt cement or semi-solid bitumen is the distance to which it will elongate before breaking when two ends of a briquette

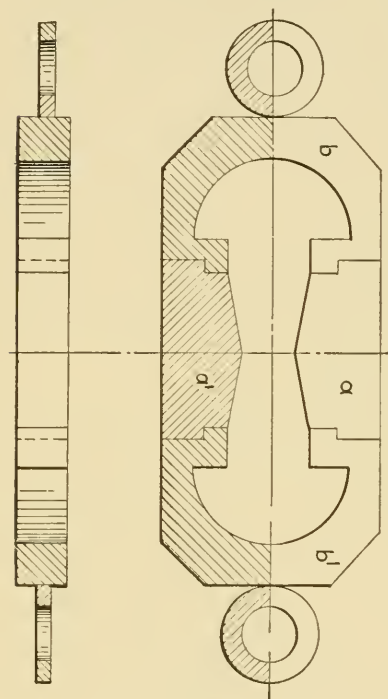


FIG. 145.—Ductility mould.

of the material are pulled apart at a specified rate of speed and at a specified temperature. When the conditions of the test are not specifically mentioned, the rate and the temperature are understood to be 5 cm. per minute at 25°C. (77°F.).

2. MOLD.—The mold shall be as shown in Fig. 145. It shall be made of brass, the ends *b* and *b'* being known as clips, and the parts *a* and *a'* as sides of the mold. The dimensions of the mold shall be as follows:

Total length (internal).....	7.45 to 7.55 cm.
Distance between clips.....	2.97 to 3.06 cm.
Width of clips at mouth.....	1.98 to 2.02 cm.
Width of briquette at minimum cross-section (half way between clips)....	0.99 to 1.01 cm.
Thickness of briquette throughout....	0.99 to 1.01 cm.

3. **WATER BATH.**—The water bath shall be maintained at a temperature not varying more than 0.1°C. from 25°C. (77°F.). The volume of not varying more than 0.1°C. from 25°C. (77°F.). The volume of water shall be not less than 10 liters and the sample shall be immersed to a depth of not less than 10 cm. and shall be supported on a perforated shelf not less than 5 cm. from the bottom of the bath.

4. **TESTING MACHINE.**—Any apparatus may be used for pulling the briquette of bitumen apart that is so constructed that the briquette will be continually immersed in water and the two clips pulled apart at a uniform rate of speed of 5 cm. per minute.

5. **MELTING AND MOLDING.**—The asphalt cement or bituminous material to be tested shall be completely melted at such a temperature that it will be thoroughly fluid—with ordinary paving asphalt cement this is about 160°C. (320°F.). It shall then be strained through a 50-mesh sieve and, after a thorough stirring, poured into the mold. The mold shall be assembled on a brass plate and so as to prevent the material under test from sticking, the surface of the plate and the interior surfaces of the side pieces *aa'* of the mold shall be thoroughly amalgamated. In filling the mold care shall be taken not to disarrange the parts and thus distort the briquette. In filling, the material shall be poured in a thin stream back and forth from end to end of the mold until it is more than level full. It shall then be left to cool to room temperature and then placed in water maintained at 25°C. (77°F.) for 30 min., after which the excess of bitumen shall be cut off by means of a hot putty knife or spatula so that the mold shall be just level full.

7. **KEEPING AT STANDARD TEMPERATURE.**—The brass plate and mold, with briquette, shall then be placed in the water bath and kept at a temperature of 25°C. (77°F.) for at least $1\frac{1}{2}$ hr., when the briquette shall be removed from the plate and the side pieces detached.

8. **TESTING.**—The rings at each end of the clip shall then be attached to the pins or hooks in the ductility machine and the two clips pulled apart at a uniform rate of 5 cm. per minute (± 5 per cent). While the test is being made, the water in the tank of the ductility machine shall cover the sample by at least 2.5 cm. and shall be kept continuously at a temperature within 0.5°C. of 25°C. (77°F.). When the specimen of bituminous material breaks, the distance from the original position of the clip shall be measured, and shall be known as the ductility. The average of three tests shall be taken, excepting that any abnormal result shall be rejected.

285. Test for Specific Gravity.—The Test for Specific Gravity is useful mostly as a means of identifying bituminous materials and insuring uniformity of supply from a given source. The American Society for Testing Materials Tentative Methods, D70-20T, and D71-20T, are respectively as follows:

SPECIFIC GRAVITY OF ROAD OILS, ROAD TARs, ASPHALT CEMENTS AND SOFT TAR PITCHES

1. DEFINITION.—The specific gravity of road oils, road tars, asphalt cements and soft tar pitches shall be expressed as the ratio of the weight of a given volume of the material at 25°C. (77°F.) to that of an equal volume of water at the same temperature and shall be expressed thus:

Specific gravity 25°/25°C. (77°/77°F.)

2. APPARATUS.—The determination of specific gravity shall be made with a pyknometer or weighing bottle, Fig. 146, which shall consist of a straight-walled glass tube approximately 70 mm. long and 22 mm. in diameter, carefully ground to receive an accurately fitting solid glass stopper with a hole of 1.5 to 1.7 mm. bore in place of the usual capillary opening. The lower part of the stopper is made concave in order to allow all air bubbles to escape through the bore. The depth of the cup-shape depression shall be about 4.8 mm. at the center. The stoppered tube should have a capacity of about 24 c.c. and when empty should weigh not over 35 g.

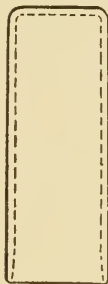


FIG. 146.—
Pyknometer.

3. METHOD.—Before making a determination, the pyknometer with stopper shall first be calibrated by weighing it clean and dry upon an analytical balance. This weight is called *a*. It shall then be filled with freshly boiled distilled water at a temperature of 25°C. (77°F.), the stopper firmly inserted, all surplus moisture wiped from the surface with a clean dry cloth and again weighed. This weight is called *b*.

4. MATERIALS WHICH FLOW READILY.—When determining the specific gravity of road oils or road tars which flow readily, the material shall be brought to a temperature of 25°C. (77°F.) and poured into the pyknometer until it is full, with care to prevent the inclusion of air bubbles. The stopper is then firmly inserted and all excess of material forced through the opening is carefully removed with a clean dry cloth. The pyknometer and contents are then weighed and the weight is called *c*. The specific gravity of the material shall be calculated from the formula:

$$\text{Specific gravity} = \frac{c - a}{b - a}$$

5. MORE VISCOUS MATERIALS.—When determining the specific gravity of tar and asphalt products which are too viscous for the method described in Sec. 4, a small amount of the material shall be brought to a fluid condition by the gentle application of heat, care being exercised to prevent loss by evaporation. When sufficiently fluid, enough is poured into the clean dry pyknometer to about half fill it. Precautions shall be taken to keep the material from touching the sides of the tube above

the final level and to prevent the inclusion of air bubbles. The tube should be slightly warmed before filling. The pyknometer and contents are then cooled to room temperature and weighed with the stopper. This weight is called *c*. The pyknometer is next removed from the balance, filled with freshly boiled distilled water, and the stopper firmly inserted. It is then completely immersed for not less than 30 min. in a beaker of distilled water maintained at 25°C. (77°F.) after which it is removed, and all surplus water is wiped off with a clean cloth. It is immediately weighed. This weight is called *d*. The specific gravity of the material shall be calculated from the formula:

$$\text{Specific gravity} = \frac{c - a}{(b - a)(d - c)}$$

6. PRECAUTIONS.—When making the specific-gravity determination it is important that:

(a) Only freshly boiled distilled water shall be used.

(b) When weighing the pyknometer completely filled, the temperature of its contents shall be within 1°C. (1.8°F.) of 25°C. (77°F.).

(c) Precautions shall be taken to prevent expansion and overflow of the contents from the heat of the hand when wiping the surface of the pyknometer.

(d) The presence of all air bubbles shall be eliminated in filling the pyknometer and inserting the stopper.

(e) Weighings shall be made quickly after filling the pyknometer and shall be accurate to 1 mg. A number of trial fillings and catch weights may be necessary to obtain the desired degree of accuracy.

(f) To prevent breakage of the pyknometer when cleaning it out after a determination has been made upon a very viscous or semi-solid material, it will be found advisable to warm it in an oven at not over 100°C. until most of the material may be poured out and then to swab it with a piece of soft cloth or cotton waste. When cool it may be finally rinsed with carbon disulfide, benzol or other solvent and wiped clean.

7. ACCURACY.—The limit of accuracy of the test is ± 0.005 specific gravity.

SPECIFIC GRAVITY OF ASPHALTS AND TAR PITCHES SUFFICIENTLY SOLID TO BE HANDLED IN FRAGMENTS

1. DEFINITION.—The specific gravity of asphalts and tar pitches shall be expressed as the ratio of the weight of a given volume of the material at 25°C. (77°F.) to that of an equal volume of water at the same temperature and shall be expressed thus:

$$\text{Specific gravity } 25^{\circ}/25^{\circ}\text{C.}(77^{\circ}/77^{\circ}\text{F.})$$

2. APPARATUS.—The determination of specific gravity shall be made with an analytical balance equipped with a pan straddle or other stationary support (Fig. 147).

3. **TEST SPECIMEN.**—The test specimen shall be a cube of the material measuring approximately $\frac{1}{2}$ in. to the edge. It shall be prepared by melting a small sample of the material by the gentle application of heat, care being exercised to prevent loss by evaporation, and pouring when sufficiently fluid into a $\frac{1}{2}$ -in. brass cubical mold, which has been amalgamated with mercury and which is placed on an amalgamated brass plate. Precautions should be taken to prevent the inclusion of air bubbles. The hot material should slightly more than fill the mold and when cool the excess may be cut off with a hot spatula. The specimen shall be removed from the mold when cooled to room temperature.

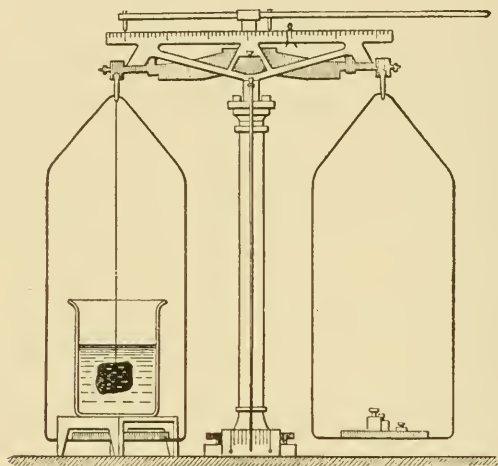


FIG. 147.—Analytical balance equipped with pan straddle.

4. **METHOD.**—The balance shall first be tared with a piece of fine waxed silk thread sufficiently long to reach from the hook on one of the pan supports to the straddle or rest. The test specimen shall then be attached to the thread, so as to be suspended about 1 in. above the straddle from the hook on the pan support, and weighed. This weight is called *a* and shall be accurate to 0.1 mg. The specimen, still suspended by the thread, shall then be weighed completely immersed in freshly boiled distilled water at 25°C. (77°F.) $\pm 1^\circ\text{C}$. (1.8°F.), adhering bubbles being first removed with a fine wire. This weight is called *b* and shall also be accurate to 0.1 mg.

The specific gravity of the material shall be calculated from the formula:

$$\text{Specific gravity} = \frac{a}{a - b}$$

5. **ACCURACY.**—The limit of accuracy of the test is ± 0.005 specific gravity.

CHAPTER XV

SPECIFICATIONS AND METHODS

286. General Information.—Specifications followed by various highway engineers for bituminous materials differ greatly. While no uniform practice has as yet been developed, there are certain typical specifications and methods that may be outlined. In the following paragraphs free use has been made of U. S. Department of Agriculture *Bulletins* 314 and 691, also American Society for Testing Materials Tentative Specifications. In the case of dust palliatives, materials for cold patching, and for cold surface treatments, there are many proprietary products on the market, some of which, while not meeting the specifications contained herein, will give good results. This can be determined only by experimental use. Three classes of tars are in common use (see *Technical Paper* 268, Bureau of Mines, 1922—"Preparation and Uses of Tar and its Simple Crude Derivatives."); water-gas tar, coke-oven tar and gas-house tar. The first named contains the least free carbon of the three, often less than 1 per cent. Gas-house tar sometimes contains as much as 30 per cent free carbon and coke-oven tar up to 15 per cent. The specific gravity generally increases with the percentage of free carbon. Specifications for tars may be separated into two classes, those for low-carbon tars and those for high-carbon tars.

Bituminous applications for both surface treatment and for penetration work should be made only when the roadways are dry; and also it is well to make them only during hot weather. Some unsatisfactory results have been attributed to the fact that temperatures less than 50°F. were prevailing during the time of application. Contractors owning equipment such as that illustrated in Fig. 148, charge usually between 1 and 2 cts. per gallon for applying bituminous materials. There is a question as to which are the better, asphalts or tar products. Good results can be obtained with either. The cost per gallon depends much upon local conditions of supply. The cost per unit area of roadway per year depends upon how much area a

gallon will cover and upon the time that may elapse before further bituminous treatment is necessary. Engineers should determine what material best meets their local conditions, by first investigating prices and then experimenting on the roadways with those products which appear to be the most favorable. For bituminous mixtures (sand or other aggregate and bituminous cement mixed after heating), there are certain methods and physical tests, to be described in a subsequent chapter, which,

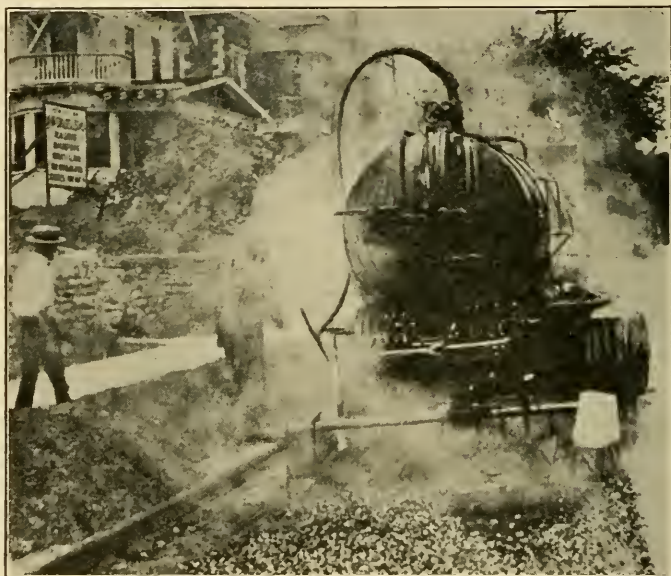


FIG. 148.—Pressure distributor applying bituminous material on penetration roadway construction.

taken in connection with the specifications outlined for bituminous cement, make it possible to design these mixtures in the laboratory so as to meet satisfactorily any given local conditions.

287. Dust Palliatives.—Dust palliatives need not have a high binding value since they are not expected to build up a bituminous mat on the road surface.

The oil may be applied without heating and the application should preferably be made by means of a pressure distributor at the rate of from $\frac{1}{8}$ to $\frac{1}{3}$ gal. per square yard. No cover of earth, sand, gravel, or stone chips should be necessary. The number of applications required to lay the dust successfully

throughout an entire season will depend upon traffic and climatic conditions; one may prove sufficient, but three or four may be required.

The accompanying petroleum specification, Table XXXI, is intended to cover some crude petroleums, heavy petroleum distillates, and light fluid residual petroleums. No specification is given for a tar product because the tar manufacturers generally do not recommend their materials for use as dust palliatives.

TABLE XXXI.—DUST PALLIATIVES

The materials shall be homogeneous	Petroleum product
Water.....	0.0 per cent
Specific gravity 25°/25°C. (77°/77°F.)	Not more than 0.940
Specific viscosity.....	At 25°C. (77°F.) not more than 10
	Flash point not less than 100°C. (212°F.)
	Loss at 163°C. (325°F.) 5 hr., not more than 15 per cent
	Float test of residue at 32°C. (89.6°F.)—liquid
Total bitumen (soluble in carbon disulfide).....	Not less than 99.8 per cent.

288. Mat Construction.—Sometimes dust palliatives are used as primers in the cold surface treatment of roads, especially for shell or gravel roads. A primer coat should be permitted to soak in undisturbed for from 18 to 24 hr., after which it should be given a very light covering of stone chips or sand. This should be followed in a few days by a heavier bituminous product. This double treatment gives somewhat longer service than when only a heavier product is used though a very satisfactory wearing mat or carpet can be obtained by the latter alone.

Materials used for cold surface treatment are usually more viscous fluids than dust palliatives and should possess considerable binding value. For hot treatment still heavier materials are

used—of such viscosity that, in order to apply them, they have to be heated to between 200 and 250°F., whether oils or tars. The heavier the oil or tar product the thicker the mat which can be obtained. With thin fluids, fine dustless screenings or sand may be used as a cover. As heavier products are used the broken stone may be increased in size up to $\frac{3}{4}$ or 1 in., but should still be dustless; or gravel may be used up to $\frac{1}{2}$ -in. size. After applying such coarse materials it is well to roll the roadway.

For a first treatment, from $\frac{1}{3}$ to $\frac{1}{2}$ gal. of bituminous material should be used. A hot application will generally, with some patching from time to time, last 2 years, cold applications usually do not last so long. For subsequent treatments from $\frac{1}{10}$ to $\frac{1}{5}$ gal. per square yard should suffice. From 5 to 10 lb. of sand, stone or gravel should be used per square yard for from $\frac{1}{10}$ to $\frac{1}{4}$ gal. of bituminous material; from 10 to 15 lb. for $\frac{1}{4}$ to $\frac{1}{3}$ gal. per square yard; and 15 to 25 lb. for $\frac{1}{3}$ to $\frac{1}{2}$ gal. For city use it is well to use a slight excess of sand, stone or gravel so that there may be no free fluid to be tracked over the walks and into the houses.

A successful treatment requires that the road surface be in a good state of repair, well consolidated, and thoroughly swept for the removal of dust and detritus. Newly constructed and reconstructed roads should be permitted to consolidate under traffic prior to being treated. Specifications are given in Tables XXXII (A) and (B).

289. Cold Patching.—Bituminous materials for cold patching do not differ greatly from those used for cold surface treatment. They are slightly heavier and not quite so fluid. As with those used for cold surface treatment, there are a great number of emulsified bitumens, cut-backs, etc., which are sold under various trade names for cold patching.

For surfaces breaks and shallow depressions, or those which in general do not exceed $\frac{1}{2}$ in. in depth a patch may be made by first sweeping and then painting the bottom of the depression with the liquid material, and scattering over it a sufficient amount of stone chips to fill the depression.

In repairing deeper depressions and holes, the old material should be removed to obtain a clean bottom. A mixture of graded broken stone with just a sufficient amount of bituminous material to coat each particle thoroughly should be prepared, and firmly tamped into the hole to form a neat patch in the surface.

TABLE XXXII(A).—MAT CONSTRUCTION TAR PRODUCTS

The material to be homogeneous	For cold application		For hot application	
	Low-carbon tar	High-carbon tar	Low-carbon tar	High-carbon tar
Water—not more than	2.00 per cent	2.00 per cent	0.00 per cent	0.00 per cent
Specific gravity at 25°/25°C. (77°/77°F.)	1.10 to 1.14	1.14 to 1.18	1.14 to 1.18	1.20 to 1.26
Specific viscosity, Engler, 50 c.c. at 40°C. (104°F.)	20 to 35	8 to 20		
Float test at 32°C. (89.6°F.) .....	.....	.....	60 to 150 sec.	60 to 150 sec.
Distillation test on water-free material				
Total distillate by weight, zero to 170°C. (32 to 338°F.) ..	Not more than 2.00 per cent	Not more than 7.00 per cent	Not more than 0.00 per cent	Not more than 0.00 per cent
Total distillate by weight, zero to 235°C. (32 to 455°F.) ..	Not more than 15.00 per cent	Not more than 18.00 per cent	Not more than 4.00 per cent	Not more than 10.00 per cent
Total distillate by weight, zero to 270°C. (32 to 518°F.) ..	Not more than 30.00 per cent	Not more than 28.00 per cent	Not more than 13.00 per cent	Not more than 15.00 per cent
Total distillate by weight, zero to 300°C. (32 to 572°F.) ..	Not more than 40.00 per cent	Not more than 35.00 per cent	Not more than 26.00 per cent	Not more than 25.00 per cent
Residue, by weight	Not less than 60.00 per cent	Not less than 65.00 per cent	Not less than 74.00 per cent	Not less than 75.00 per cent
Specific gravity at 25°/25°C. (77°/77°F.) of total distillate to 300°C. (572°F.) .....	.....	Not less than 1.01	.....	Not less than 1.03
Softening point (cube-in-water method) of residue from distillation test.	Not more than 70°C. (158°F.)	Not more than 60°C. (140°F.)	Not more than 75°C. (167°F.)	Not more than 75°C. (167°F.)
Free carbon	Not more than 5.00 per cent	4.00 to 12.00 per cent	Not more than 5.00 per cent	12.00 to 22.00 per cent

TABLE XXXII(B).—MAT CONSTRUCTION ASPHALTIC MATERIALS

The material to be homogeneous	For cold application		For hot application
	Certain types of crude or topped petroleums and cut-back oil asphalts		
Water.....	0.00 per cent		Residual asphaltic petroleums, cut-back oil asphalts, and some crude asphaltic petroleums
Specific gravity 25°/25°C. (77°/77°F.)....	0.935 to 0.970		0.00 per cent
Specific viscosity at 25°C. (77°F.).....	80 to 120		Not less than 0.980
Float test at 32°C. (89.6°F.).....	.....		Not less than 60 sec.
Flash point.....	Not more than 50°C. (122°F.)		Not less than 80°C. (176°F.)
Loss at 163°C. (325°F.) 5 hr.....	Not more than 30 per cent		Not more than 15 per cent
Float test of residue at 50°C. (122°F.)....	Not less than 90 sec.		Not less than 110 sec.
Total bitumen (soluble in carbon disulfide)	Not less than 99.5 per cent		Not less than 99.5 per cent

A thin layer of sand or screenings over the patch will prevent it from picking up under traffic.

For badly worn roads a cold patch mixture made with stone ranging in size from 1 to 2 in. may be used for repairing the worst spots. The roadway should then be gone over a second time, using 1-in. stone for slight depressions and for finishing off the coarse stone patches.

In Fig. 149, is illustrated the cold repair, by the penetration method, of a deep rut. After cleaning the surface, 2½-in. stone



FIG. 149.—Cold patching.

as shown, was rolled into the rut. This was lightly sprinkled with a cold patch bitumen. In the left of the photograph is a pile of 1-in. stone which was mixed with cold liquid material at a central plant. This is spread over the base stone and rolled, then dusted with sand. Typical specifications for cold patch material are given in Table XXXIII.

290. Penetration and Mixed Construction.—Asphaltic materials used for penetration and mixed construction are either run to grade in the original distillation or are fluxed to definite degrees of hardness in order to meet various local conditions. Tar products are generally straight run to the desired consistency. For penetration construction, asphalts vary in hardness

TABLE XXXIII.—COLD PATCHING

The material to be homogeneous	Low-carbon tar	High-carbon tar	Cut-back oil asphalts
Water—not more than.....	2.00 per cent	2.00 per cent	0.00 per cent
Specific gravity at 25°/25°C. (77°/77°F.).....	1.10 to 1.14	1.15 to 1.20	935 to 1,000
Specific viscosity, Engler, 50 c.c.....	At 40°C. (104°F.) 35 to 40	At 40°C. (104°F.) 40 to 70	At 25°C. (77°F.) 50 to 120
	Total Distillate by weight Zero to 170°C. (32° to 338°F.) Not more than 3.00 per cent	4.00 to 12.00 per cent	Flash point—not more than 50°C. (122°F.)
	Zero to 235°C. (32° to 455°F.) Not more than 20.00 per cent	8.00 to 20.00 per cent	Loss at 163°C. (325°F.), 5 hr.—25 to 36 per cent
	Zero to 270°C. (32° to 518°F.) Not more than 30.00 per cent	18.00 to 30.00 per cent	
	Zero to 300°C. (32° to 572°F.) Not more than 40.00 per cent	Not more than 35.00 per cent	Penetration of residue at 25°C. (77°F.), 100 g., 5 sec.—not more than 100.
	Residue by weight Not less than 60.00 per cent	Not less than 65.00 per cent	
	Softening point (cube-in-water method) of residue from distillation test, Not more than 75°C. (167°F.)	Not more than 75°C. (167°F.)	
Total bitumen (solution in carbon disulfide)	Not less than 95.00 per cent	78 to 88 per cent	Not less than 99.80 per cent

as shown by the penetration test, from 90 to 150, the hardest being used in warm localities and the material decreasing in hardness for colder and colder climatic conditions. Likewise with products for mixed construction, except that the range of the penetration test should be limited to 30 as a minimum for warm and 70 as a maximum for cold climates, especially with fine aggregate mortar mixtures, though sometimes with one size stone used in coarse mixtures as high as 90 penetration is used, the practice generally being to use softer asphalt with coarse mixtures than with fine. A 10-point range may be allowed when specifying asphalts below 90 penetration, and a range of 30 points for cements above 90 penetration.

It is well to limit tar products for penetration construction to a minimum softening point (cube-in-water method) of 100°F. for cold climates and to a maximum of 120°F. for warm climates. There are, however, some products sold under trade names which, though varying from these limits, give good results. On account of their high susceptibility to temperature ranges, pitches are not often used in fine mortar mixtures, though to a greater extent in coarse stone mixed construction. For penetration work asphalts should be applied at temperatures ranging from 275 to 325°F., depending upon the degree of hardness of the material. Pitches do not have to be heated to as high temperatures, 225 to 275°F. being sufficient. Care should be taken with both asphalts and tar products, not to over-heat and injure the material. The details of mixed construction will be taken up in the next chapter.

For penetration work the hot material should be applied to the upper or wearing course of compacted broken stone at the rate of about $\frac{3}{4}$ gal. per square yard per inch depth of stone. The application may be made by means of pouring pots or by a pressure distributor so designed that it will not produce ruts during application. The stone should pass a $2\frac{1}{2}$ -in. screen and be retained on a $1\frac{1}{2}$ -in. screen. The exact range in size should be governed by the kind and quality of rock used. The application should be followed by a sufficient amount of clean small sized broken stone (passing a 1-in. screen and retained on a $\frac{1}{2}$ -in.) to fill the surface voids when thoroughly rolled. A seal coat with the same material used for penetration should then be applied at the rate of 0.4 to 0.6 gal. per square yard and covered with just enough stone chips to absorb the excess bitumen. Roads of this character may be maintained with surface treat-

ments, which should be applied whenever the wear comes directly upon the wearing course rock.

TABLE XXXIV(A).—TAR PRODUCTS FOR PENETRATION AND MIXED CONSTRUCTION

The materials shall be homogeneous and free from water	
Specific gravity at 25°/25°C. (77°/77°F.)	Low-carbon pitch 1.16 to 1.19 High-carbon pitch 1.20 to 1.28
Softening point (cube-in-water method).	37.5 to 48.9°C. (100 to 120°F.)
Bitumen soluble in carbon disulfide.....	Low-carbon pitch, not less than 95.0 per cent High-carbon pitch, 75.0 to 88.0 per cent
Total distillate by weight	
Zero to 170°C. (32 to 338°F.).....	0.00 per cent
Zero to 235°C. (32 to 455°F.).....	Not more than 2.00 per cent
Zero to 270°C. (32 to 518°F.).....	Not more than 10.00 per cent
Zero to 300°C. (32 to 572°F.).....	Not more than 20.00 per cent
Residue by weight.....	Not more than 80.00 per cent
Softening point of residue from distillation test.....	Not more than 75°C. (167°F.)

TABLE XXXIV(B).—AMERICAN SOCIETY FOR TESTING MATERIALS TENTATIVE SPECIFICATIONS FOR ASPHALT CEMENT

Serial Designation: D99-22T to D103-22T inclusive and D135-22T.

The asphalt cement shall be homogeneous and free from water.

Penetration at 25°C. (77°F.) 100 g., 5 sec... (See note.)

Flash point (open cup)..... Not less than 175°C. (347°F.)

Loss on heating at 163°C. (325°F.), 50 g., 5 hr. Not more than 2 per cent

Penetration at 25°C. (77°F.), 100 g., 5 sec., of residue after heating at 163°C. (325°F.) as compared with penetration of asphalt cement before heating..... Not less than 60 per cent

Ductility at 25°C. (77°F.)..... Not less than 30 cm.

Proportion of bitumen soluble in carbon tetrachloride..... Not less than 99 per cent

The penetration method may be used for the construction of a wearing course, either on an old existing road or upon a specially prepared foundation. The wearing course obtained is

NOTE.—The six serial designations are identical with the exception of the one item "Penetration" which beginning with D99-22T varies as follows: "40 to 50," "50 to 60," "60 to 70," "70 to 90," "90 to 120," and "120 to 150."

from 2½ to 3 in. in thickness. It is generally assumed that 1 cu. yd. of coarse stone will cover 12 sq. yd. spread to a loose thickness of 3 in. and that this will compact 25 per cent under rolling. For the small sized broken stone which is rolled into the coarse stone after the bituminous application, 1 cu. yd. covers about 50 sq. yd. For the seal coat, about 35 lb. (usually less for tar products than for asphalts) are used per square yard. Specifications for the bituminous materials are given in Tables XXXIV(A) and (B).

291. Native Asphalts and Other Products.—The specifications that have just been given include a wide variety of products in open competition. They may be narrowed in order to restrict purchases to any one special material. It is usual to specify that oil asphalts shall contain not less than 99.5 per cent bitumen soluble in carbon disulfide. The specific gravity of oil asphalt is generally about 1.05. The harder cements usually being limited to a minimum of 1.02 specific gravity and the softer ones to a minimum of 1.00 specific gravity.

If a blown petroleum is desired, the specifications may stipulate a definite susceptibility to temperature, the following being an example:

Penetration at 32°F.....	20
Penetration at 77°F.....	40
Penetration at 115°F.....	90

whereas a straight residual asphalt of 40 penetration might run as low as 10 at 32° and as high as 300 at 115°. Most special products are sold under trade names, generally cost more than straight residual materials, and, if desired, their specifications should be obtained from the manufacturers.

If blown petroleums are to be eliminated, ductility may be specified. Straight residuals may have a ductility above 100 while blown oils often run below 30 and seldom above 40.

Two of the best known native asphalts which have been used successfully for many years are Trinidad and Bermudez. The former after being refined contains approximately 56 per cent bitumen and the latter 94 per cent. Trinidad is ordinarily used only in mixed construction while Bermudez has been given as varied use as oil asphalts. For all paving purposes these two native asphalts have to be softened by fluxing, which may be carried out at the road plant but more often is done by the refiner.

The amount of flux and the physical characteristics of the resulting cement depend upon the nature of the flux. With very heavy residuums as much as 60 lb. of flux per 100 lb. of refined asphalt may be required to give a cement of 60 penetration. There are some light residuums, though scarce, of such density that not more than 22 lb. are required per hundred in order to produce cements of 60 penetration.

The percentage of bitumen (soluble in carbon disulfide) in the cement varies with the amount of flux, the latter being practically pure bitumen. Sixty-six per cent bitumen is typical for Trinidad cement and 96 per cent for Bermudez. Ductility for either generally runs above 40. Fluxed Bermudez ranges in specific gravity at 25°C. from 1.04 to 1.05 for a penetration at 25°C. of 120 to 150, up to specific gravity 1.055 to 1.075 for penetration 40 to 50. The specific gravity at 25°C. of fluxed Trinidad for mixed construction usually lies between 1.20 and 1.27.

There are also other native solid bitumens on the market, also sands impregnated with bitumen and sold as natural rock asphalt, and in addition there are various ways of treating asphalts; as for instance, adding sulfur in various forms, slaked lime, etc. For all unfamiliar products and treatments information should be obtained directly from the advertisers. It should be borne in mind that to date an actual service test in the pavement is the only accurate means of determining how unknown bituminous cements will behave on aging or upon exposure to the elements. However, by means of the tests which have been specified in the present chapter and the Block Test described in Chap. XVI, they may be compared with well tried products, and fair inference may be drawn as to their probable behavior.

CHAPTER XVI

DESIGN OF BITUMINOUS MIXTURES

292. Bituminous Mixtures.—Just as portland cement mixtures may be divided into concretes and mortars, so may those made with asphalt cement. These, in turn, have been divided in practice into many different types. When a coarse aggregate is not graded, but is mostly of one size stone, it has generally been known as “one size stone concrete.” This type carries less cement than any other and ordinarily has been used as a binder course laid about $1\frac{1}{2}$ in. in thickness, between the base and the “topping” or wearing surface in sheet asphalt. The composition of an example is shown in Table XXXV. Also, there are shown two much used examples of concrete and topping mixtures. These two gradings fall within certain old patent claims. The “Topeka” mixture included in the table lies between the fine mortar or “topping” and the concrete. For base construction with bituminous concrete, stone up to $2\frac{1}{2}$ in. size is usually used, a typical specification being:

	PER CENT
Passing $2\frac{1}{2}$ -in., retained on 1-in. screen.....	15 to 45
Passing $1\frac{1}{4}$ -in. retained on $\frac{1}{4}$ -in. screen.....	15 to 45
Total of above two grades.....	53 to 70
Passing $\frac{1}{4}$ -in. screen.....	25 to 40
Bitumen soluble in carbon disulfide.....	4 to 7

TABLE XXXV.—BITUMINOUS MIXTURES

Composition of mixture	Binder, per cent	Concrete, per cent	Topeka, per cent	Topping, per cent
Passing 1-in. retained on $\frac{1}{2}$ -in.....	70	50		
Passing $\frac{1}{2}$ -in. retained on 10-mesh.....	20	18	25	
Passing 10-mesh retained on 20-mesh.....	5	9	20	3.0
Passing 20-mesh retained on 30-mesh.....				5.0
Passing 30-mesh retained on 40-mesh.....				8.0
Passing 40-mesh retained on 50-mesh.....		12	23	11.0
Passing 50-mesh retained on 80-mesh.....				23.5
Passing 80-mesh retained on 100-mesh.....			15	13.0
Passing 100-mesh retained on 200-mesh.....				13.0
Passing 200-mesh.....		4	8	13.0
Percentage of bitumen.....	5	7	9	10.5
Total.....	100	100	100	100.0

293. Duplicating Sieve Analyses.—Practically all mixtures that have hitherto been used throughout the United States have been prepared according to one or another of several well-known or patented formulae that call for combinations of particles, which make up an aggregate, in accordance with specified sieve analyses. Aggregates blended to conform to stated granulometric formulae are usually expensive—in some parts of the country too costly to be considered. The amount of cement to be used with these artificially graded materials is based upon the amount used in other localities with similar gradings—often a “surface area” (see also, Chap. X) formula is used. Certain mesh combinations of aggregate in one locality mixed with a definite amount of bitumen may give a satisfactory pavement. The same combinations made up of aggregate native to a distant locality may be most unsatisfactory. There are petrographic and physical qualities, other than just the size of the particles, affecting the quantity of cement required. The single factor, voidage, has a large influence on the amount of bitumen that an aggregate may successfully carry and must not be ignored. The surface area of the aggregate particles cannot be assumed to be a proper measure of bitumen requirements, because sands are known which, though graded according to identical sieve analyses, range from 40 to 55 per cent in voidage.

Sand and other fine aggregate containing particles not much in excess of $\frac{1}{4}$ in. are best for bituminous surfaces. When coarser aggregates are used, a seal coat has to be given the surface of the mixture after it is spread in order to close its pores. Any fine aggregate that makes good portland cement concrete can be used successfully in bituminous mortars, and it is no more necessary to call for expensive blending of several sands in order to meet the sieve analysis of some advertised formula than it is in the case of portland cement concrete.

294. Elimination of Binder Course.—Another element in the construction of bituminous surfaces, much used since 1886, and to which a good deal of mystery has been attached, is the binder course. Generally it has been $1\frac{1}{2}$ in. in thickness laid between the pavement base and a $1\frac{1}{2}$ -in. topping course. The binder costs almost as much as the topping course. There is no logical reason for its retention, and it should be eliminated. True, it adds to the total thickness of pavement, and therefore adds strength, but no more than can be obtained at much less cost by

increasing the thickness of the concrete base. With binder and topping aggregating 3 in. in thickness instead of a wearing surface only $1\frac{1}{2}$ in. thick the cost for patching is practically doubled. For each inch in thickness, a square yard patch requires approximately 1 cu. ft. of hot mixture.

It has been claimed that the binder course keeps moisture out of the topping, but this claim is not warranted. Some persons urge that the binder ties the topping to the concrete base, while others for this purpose use a paint coat of tar or asphalt. Still others roughen the surface of the concrete base. A properly designed bituminous topping does not need to be tied to the base; it will not only stay in place but will do so without creeping into waves and without other unreasonable deterioration.

Prior to 1886 many surfaces were laid with topping mixtures only, and also after the introduction of the binder course, engineers at various times laid topping only. Examples of these single course surfaces, of all ages up to 42 years, are still in existence and their good condition today shows that the binder course can be eliminated.

295. Normal Bitumen Requirements.—Bituminous pavements are subject to two defects: (1) cracking; (2) creeping into waves. Cracking leads to expensive maintenance, particularly during a wet slushy winter season; creeping gives a rough surface, especially in the hot summer months, sometimes to such an extent that the only remedy is the entire replacement of the surface.

There are two kinds of cracking due to very different causes. The photograph accompanying the discussion of "Impact and Rigidity," Chap. V, illustrates cracking caused by a lack of rigidity in the base. Changes in the design of the surface mixture cannot correct this type of cracking. Figure 150, pictures cracking due to incorrect mixture design. When repair patches are made in such a pavement with proper mixtures, as may be seen, the cracks do not extend through them.

Throughout the half century or so of bituminous paving practice in this country, many conjectures have been made concerning the causes of and the remedy for creeping. In sheet asphalt construction the binder course was introduced between the base and the topping, largely with the expectation of preventing this fault, but as is illustrated by the example shown in Fig. 151, a section from a street laid in 1907, waves are due to imperfect

topping mixtures and are in no wise prevented by introducing a binder course.



FIG. 150.—Cracking due to an imperfect surface mixture. These cracks appear irrespective of the type of underlying base.

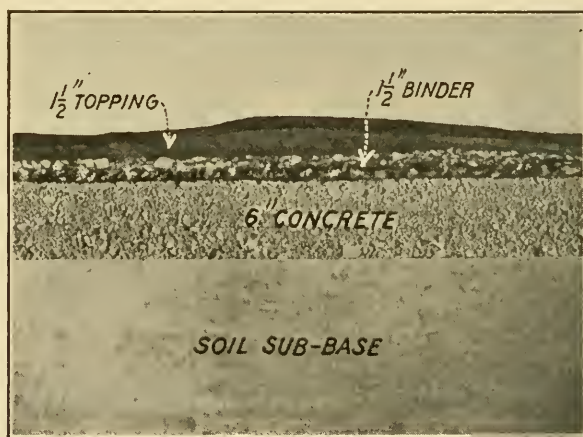


FIG. 151.—Wave in the $1\frac{1}{2}$ -in. course of a sheet asphalt. This wave is independent not only of the concrete base but also of the binder course.

As a rule, cracking and creeping are not found in the same pavement. When a cracked surface is repaired the joint around

the patch is in evidence. When a waved surface is repaired, the patch irons into the surrounding material so that it is difficult in a short time to outline the repair. Pavements fall naturally into three classes—cracked, good, and waved, though the first merges into the second and that into the third class. With this in mind, an analysis of specimens cut from a great number of streets of all ages up to 42 years, and of every conceivable aggregate grading, established the “normal mix” diagram shown in Fig. 152.

To determine the aggregate voidage in making use of this diagram, the volume of a 1,000-g. sample is measured in a graduated cylinder, each quarter of the sample being poured gently

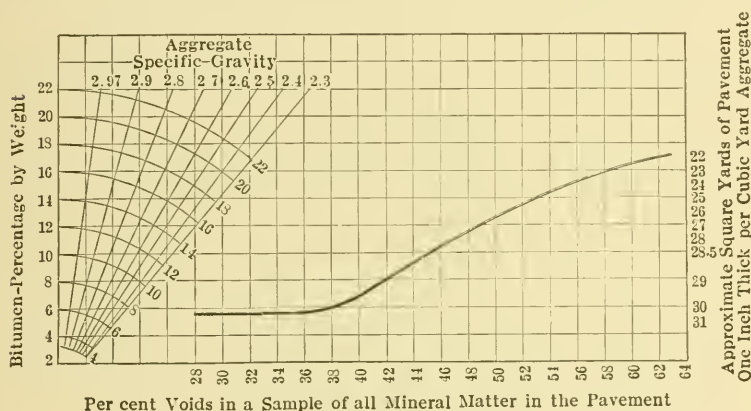


FIG. 152.

down the side of the tilted cylinder and then leveled without shaking or tamping, before pouring in the next quarter. Suppose the aggregate measures 680 c.c. Add 600 c.c. of water, cork the cylinder and shake until the aggregate is thoroughly saturated. Assume that the volume then obtained (water plus aggregate) is 970 c.c. Since 600 c.c. of this volume is water, the difference, $970 - 600$ or 370 c.c., equals the absolute volume of the aggregate, which in a loose dry state measured 680 c.c. The voidage therefore equals $680 - 370$ or 310 c.c. The percentage of voids equals $\frac{310}{680}$ or 45.6. The specific gravity of the aggregate equals

weight divided by absolute volume, or $\frac{1,000}{370} = 2.7$. According to the “normal mix” diagram, the pavement mixture using this aggregate should contain 11.3 per cent bitumen.

In order to obtain a given percentage of bitumen, the number of pounds of bituminous cement to use per 100 lb. of aggregate depends upon the purity of the cement and may be computed by the following formula:

Pounds of cement =

$$\frac{\text{weight of aggregate} \times \text{per cent of bitumen in pavement}}{\text{per cent of bitumen in cement} - \text{per cent of bitumen in pavement}}$$

Suppose the bituminous cement is but 60 per cent bitumen and a mixture containing 11.3 per cent bitumen is desired, then we have for 100 lb. of aggregate

$$\frac{100 \times 11.3}{60 - 11.3} = 23.2 \text{ lb. of cement}$$

The number of pounds of cement necessary for various percentages is given in Table XXXVI for cement which is 99.5 per cent bitumen.

TABLE XXXVI.—POUNDS OF CEMENT (99.5 PER CENT BITUMEN) TO USE PER 100 LB. OF AGGREGATE IN ORDER TO OBTAIN SPECIFIED PERCENTAGES OF BITUMEN IN THE PAVEMENT

(Formula, $\frac{100 \times \text{per cent bitumen}}{99.5 - \text{per cent bitumen}} = \text{pounds cement}$)							
Per cent bitumen in pave- ment	Pounds cement	Per cent bitumen in pave- ment	Pounds cement	Per cent bitumen in pave- ment	Pounds cement	Per cent bitumen in pave- ment	Pounds cement
5.0	5.29	7.2	7.80	9.4	10.43	11.7	13.32
5.1	5.40	7.3	7.92	9.5	10.55	11.8	13.45
5.2	5.51	7.4	8.03	9.6	10.68	11.9	13.58
5.3	5.63	7.5	8.15	9.7	10.80	12.0	13.71
5.4	5.74	7.6	8.27	9.8	10.92	12.1	13.84
5.5	5.85	7.7	8.39	9.9	11.05	12.2	13.97
5.6	5.96	7.8	8.50	10.0	11.17	12.3	14.10
5.7	6.08	7.9	8.62	10.1	11.30	12.4	14.24
5.8	6.19	8.0	8.74	10.2	11.42	12.5	14.37
5.9	6.30	8.1	8.86	10.3	11.55	12.6	14.50
6.0	6.42	8.2	8.98	10.4	11.67	12.7	14.63
6.1	6.53	8.3	9.10	10.5	11.80	12.8	14.76
6.2	6.64	8.4	9.22	10.6	11.92	12.9	14.90
6.3	6.76	8.5	9.34	10.7	12.05	13.0	15.03
6.4	6.87	8.6	9.46	10.8	12.17	13.1	15.16
6.5	6.99	8.7	9.58	10.9	12.30	13.2	15.29
6.6	7.10	8.8	9.70	11.0	12.43	13.3	15.43
6.7	7.22	8.9	9.82	11.1	12.56	13.4	15.56
6.8	7.33	9.0	9.94	11.2	12.68	13.5	15.70
6.9	7.45	9.1	10.07	11.3	12.81	13.6	15.83
7.0	7.57	9.2	10.19	11.4	12.94	13.7	15.97
7.1	7.68	9.3	10.31	11.5	13.07	13.8	16.10
				11.6	13.20	13.9	16.24

296. The Block Test.—Bituminous mixtures are composed of two elements—bitumen and mineral aggregate. The diagram just explained tells the amount of bitumen for “normal mix” but this is no guarantee that the aggregate used will give a satisfactory pavement. For instance, standard Ottawa sand consists of polished grains, almost round, practically all of one size (passing the No. 20 sieve and retained on the No. 30), like so many miniature marbles. If this sand is mixed with cement in

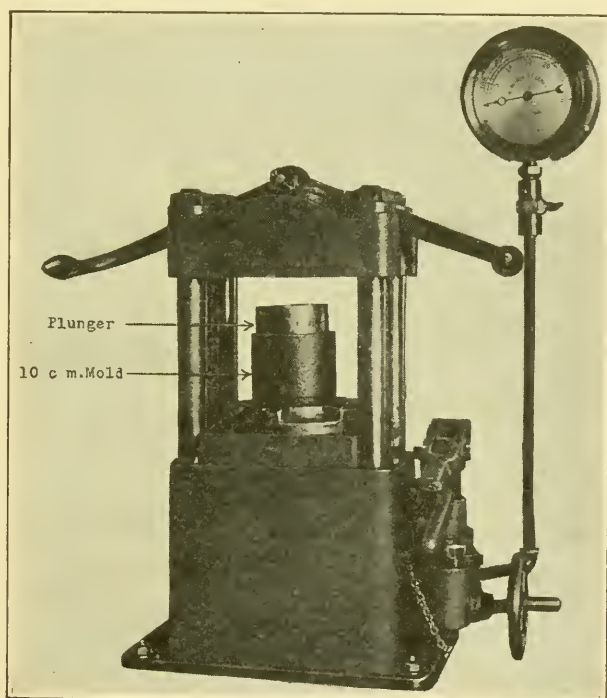


FIG. 153.—Ten-centimeter (approximately 4-in.) mold and small hydraulic press used in compressing the hot mixtures into cylindrical blocks for testing.

accordance with the diagram and a sample slab placed in the sun it will be found that the cement will soften with a tendency to run from between the particles. The interstitial spaces are too large. Thus of two aggregates, having equal voidages, one may be satisfactory for pavements and the other not. Also there are aggregates which, though unsatisfactory with a “normal mix,” may meet given requirements by certain changes, to be described in subsequent paragraphs, in either the bitumen or

aggregate or both. The diagram establishes a basic quantity of bitumen for any aggregate that it is desired to investigate. A test is then necessary to determine the probable behavior of the mixture thus made and to further determine what can be done to improve it, and for this purpose the "Block Test" has been developed.

Bearing in mind the three classes of pavements; cracked, good, and waved, specimens were cut from streets and com-

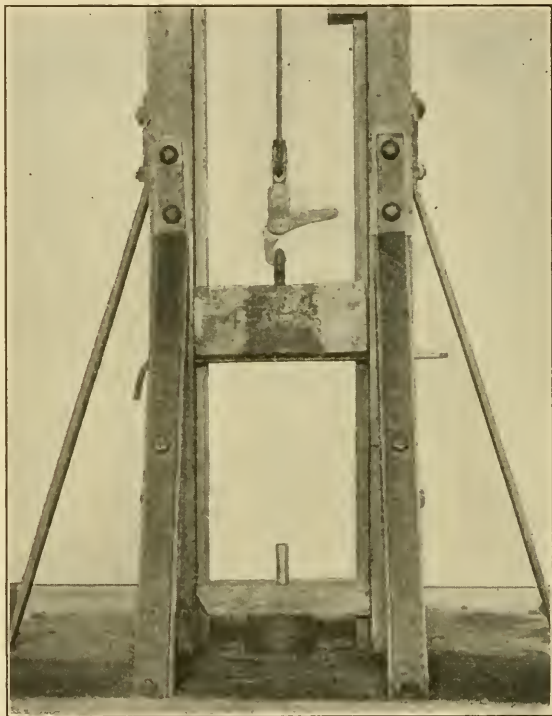


FIG. 154.—Apparatus for making the Block Test. The blocks are 10 cm. in diameter and 6 cm. high. The pin is a piece of $\frac{3}{4}$ -in. drill steel. The weight which falls through a height of 64 cm. weighs 20 kilos (approximately 45 lbs.).

pressed into blocks in the mold shown in Fig. 153. The mold is a piece of 4-in. steel pipe and turns out blocks 10 cm. in diameter. Blocks representing the various streets were broken or punctured by a pin upon which a weight was dropped. The apparatus for this is shown in Fig. 154. The pin is $\frac{3}{4}$ in. in diameter. The blow is struck by the weight of 20 kg. (approximately 45 lb.) falling through a distance of 64 cm. (2 ft.). A small hydraulic

press of 10-ton capacity is large enough for making the blocks, as an 8-ton pressure on the 4-in. plunger in the mold gives blocks equal in density to specimens cut from roadways. If no press is available the testing apparatus may be substituted. Dropping the 45-lb. weight 15 times through a height of 5 ft. onto the 4-in. plunger gives satisfactory compression.

Blocks to be tested, though of different mixtures, should be of one height, 6 cm. To determine the number of grams of hot mixture to use in order to obtain this height a trial is made with 1,000 g. and the desired weight taken from Table XXXVII. The 1,000-g. block is convenient also for determining the specific gravity of the compressed mixtures. The tables gives this information. In carrying out the block test, five blocks are used for each mixture investigated, one to be tested at each temperature, 32, 50, 80, 110, and 140°F. This, in order to show the behavior of the mixture when exposed to summer and winter conditions as well as to average conditions. For work of particular importance, three blocks should be tested at each temperature and the average result considered.

TABLE XXXVII.—SPECIFIC GRAVITY OF 1,000-G. BLOCK OF GIVEN HEIGHT

$$\text{Formula: Specific gravity} = \frac{1,000 \text{ (weight of block)}}{78.54 \text{ (area of base)} \times \text{height}}$$

GRAMS OF MIXTURE TO GIVE A 6-CM. HEIGHT WHEN A 1,000-G. BLOCK MEASURES A GIVEN HEIGHT.

$$\text{Formula: Weight} = 471.24 \text{ (volume of 6-cm. block)} \times \text{specific gravity}$$

Height of 1,000-g. block, centimeters	Specific gravity	Grams to give 6-cm.	Height of 1,000-g. block, centimeters	Specific gravity	Grams to give 6-cm.
5.0	2.55	1,200	6.0	2.12	1,000
5.1	2.50	1,176	6.1	2.09	983
5.2	2.45	1,154	6.2	2.05	968
5.3	2.40	1,132	6.3	2.02	952
5.4	2.36	1,111	6.4	1.99	937
5.5	2.32	1,091	6.5	1.96	923
5.6	2.27	1,071	6.6	1.93	909
5.7	2.23	1,052	6.7	1.90	895
5.8	2.19	1,034	6.8	1.87	882
5.9	2.16	1,017	6.9	1.84	869

297. Standards for Reference.—Typical specimens are shown in Fig. 155, of the three classes of pavements *A* cracked; *B*, good; and *C*, waved. In interpreting the Block Test not only the number of blows but also the appearance of the tested blocks must be considered. Mixtures representing cracked pavements are friable, particularly at the colder temperatures, though at the higher temperatures results generally compare not unfavorably with those of good mixtures at 80°F. or below. Blocks representing waved pavements are soft at the higher temperatures, the pin often penetrating with no cracking of the blocks, while

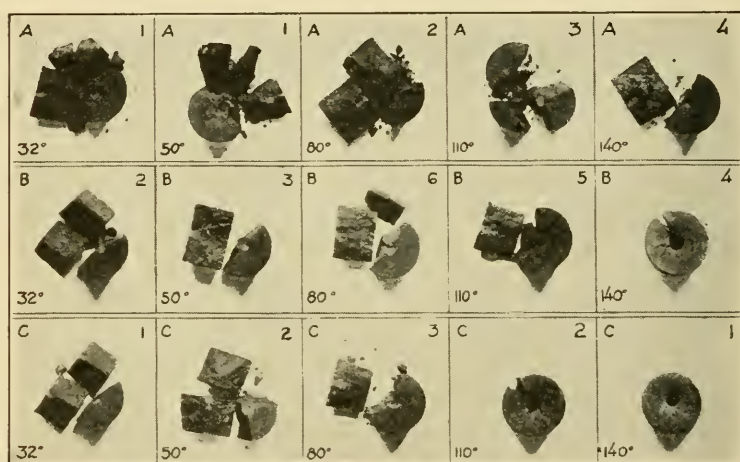


FIG. 155.—Temperatures recorded in lower left corners; number of blows, upper right.

at colder temperatures they do not show greatly different results from good mixtures. Having established a set of standards, based upon proven mixtures from existing pavements, investigation may proceed with new and untried mixtures.

298. Filler.—While it may be said that pavement mixtures consist of two elements, bitumen and aggregate, the latter contains in reality a third component—which is filler, being either limestone dust, portland cement, slate dust, or other finely divided material. The purpose of the filler is to decrease the sizes of the individual voids which make up the total voidages of the aggregates. This is made clear by reference to the blocks shown in Fig. 156, in which the aggregate is standard Ottawa sand. It has been stated previously, that when this sand is

mixed by itself with a bituminous cement, the mixture will not hold together in a slab at even slightly above room temperatures. The voidage of the straight sand is about 42 per cent. As the proportion of dust is increased, the voidage of the mixture decreases to a minimum, and then with the addition of more dust increases, until, as the combination approaches zero sand and 100 per cent dust, the voidage will be that of straight dust, which may be above 60 per cent. A great deal of filler, almost 40 per cent, is required before any appreciable stability is obtained with Ottawa sand mixtures. For most aggregates suitable for road

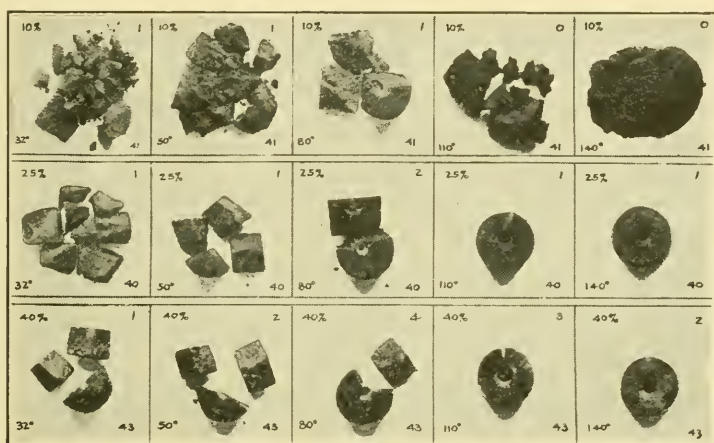


FIG. 156.—Effect of filler. Ottawa sand with 10, 25, and 40 per cent lime-stone dust. Filler percentages shown in upper left hand corners; Fahrenheit temperatures lower left corners; number of blows upper right; and aggregate voidages lower right.

work seldom or never is more than 20 per cent dust necessary and that proportion is best which gives a voidage for the combination, greater than the minimum possible, and yet just under the voidage of the straight aggregate.

However the statement often made that dust is added to sand for bituminous mixtures in order to reduce the voidage is not absolutely correct. Generally, there is little or no change in the total volume of the voids, but the individual voids between the aggregate particles are greatly multiplied in number by the addition of dust. The bituminous cement is thereby spread throughout the mixture in very thin films, and is less susceptible to temperature changes than if it were sub-divided among but a few void spaces, each space being of relatively large volume.

299. Quantity of Bitumen.—The effect of changing the amount of bitumen used with an aggregate is illustrated in Fig. 157. The second series of blocks contains 8 per cent bitumen in accordance with the requirements of the "normal mix" diagram. The first series contains but 5 per cent and the blocks are friable, the third contains 10 per cent and the blocks are soft. Abnormal quantities of bituminous cement have a bulking effect analogous to water in the case of portland cement mixtures. Using the minimum possible amount of cement gives, on one side of the dividing line, blocks of maximum volume for a given amount of

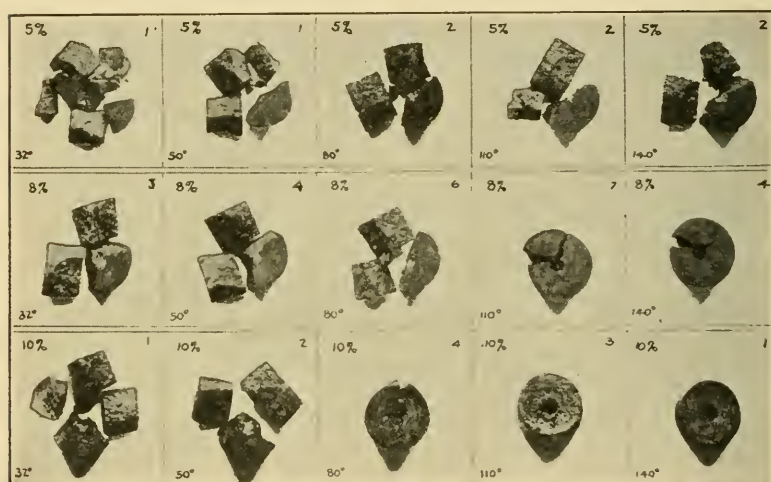


FIG. 157.—Quantity of bitumen. Test of blocks containing 5, 8, and 10 per cent bitumen; 8 per cent being correct. Bitumen percentages recorded in upper left corners; Fahrenheit temperatures, lower left; and number of blows, upper right.

aggregate. As the cement is increased the blocks decrease in volume to a minimum and then, as the cement is further increased, the volume of the blocks increases. The proper amount of bitumen to choose depends upon the use to which the mixture is to be put. If the base of the pavement is firm and lateral support is provided for the surface, the latter may be a hard, dry mix. For a flexible base the mixture should be a relatively soft one so that it will bend and not crack. The thicker the surface course is laid the harder and drier may be the mix.

300. Penetration of Bituminous Cement.—Changing the penetration of the bituminous cement, the quantity of bitumen

remaining constant, accomplishes somewhat the same result as changing the amount of bitumen, the penetration remaining constant. In Fig. 158, are shown three series of blocks, all containing the same aggregate and equal amounts (9 per cent) of bitumen. In the first series, the bituminous cement had a penetration of 20, the second series, 55, and the third, 110. With the low penetration series, the block test shows good results at high temperatures; while with the high penetration series, good results are shown at low temperatures. Accordingly, before being satisfied with the average results obtained with

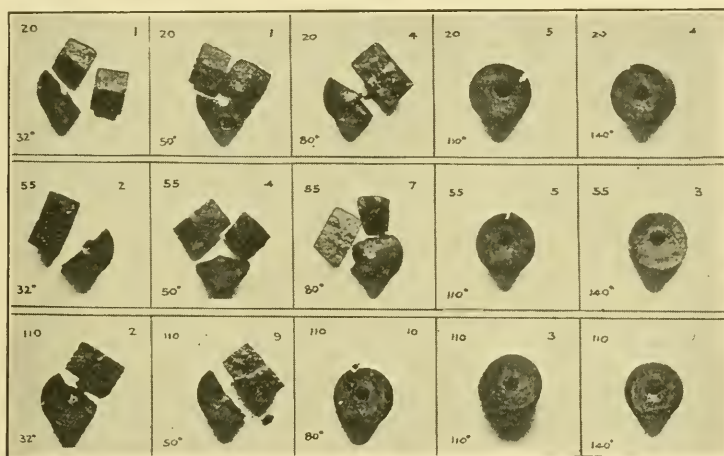


FIG. 158.—Effect of increasing the penetration. Bitumen percentage constant and equal to 9 per cent. Penetration recorded in upper left corners, number of blows in upper right, and Fahrenheit temperatures in lower left.

a normal amount of cement of medium penetration, it is well to carry out the block test with a sub-normal amount of cement of high penetration and also with an above-normal amount of cement of low penetration. By thus varying the factors that influence the design of bituminous mixtures it is possible to finally achieve the combination giving the most uniform and satisfactory results at temperatures ranging from 32 to 140°F.

301. Different Aggregates.—As shown by the “normal mix” diagram, the amount of bitumen, depending upon the character of the aggregate, may vary within wide limits, being about 7 per cent for low voidage aggregates and almost three times that percentage for extremely high voidages. When a very fine sand or dust is mixed with a bituminous cement, the bulk of the ingre-

dients shrinks to a great extent, so that as little as 22 sq. yd. of paving 1 in. thick may result from 1 cu. yd. of aggregate. For coarser materials the shrinkage is less; and with very low voidage aggregates as much as 31 sq. yd., 1 in. thick, may be obtained per cubic yard of mineral aggregate.

With aggregates commonly used for roadways the specific gravities of the resulting pavements lie within relatively narrow limits; about specific gravity 2.5 for mixtures with aggregates of voidages less than 35, and about specific gravity 2.0 for those above 45. Specific gravities may be interpolated between 2.0 and 2.5 for mixtures made with aggregates having voidages between 35 and 45. These specific gravities correspond to a range in pavement weights of from 94 to 117 lb. per square yard 1 in. thick.

The preceding data, while cited in order to show primarily, the extent to which the character of the aggregate enters into the problem of design, may be used for approximate estimating purposes. Data may be affected by aggregate qualities other than voidage alone; and also it is to be remembered that too little and too much bitumen have a bulking effect thereby affecting normal specific gravities. For precise information, blocks should be made and measured as described under "Block Test."

In Figs. 159 and 160, are shown mixtures made with two different sands. One, a $\frac{1}{4}$ -in. sand, 40 per cent retained on the No. 20 sieve and 5 per cent passing the No. 80; the other, a No. 10 sand, 5 per cent retained on the No. 20, and 25 per cent passing the No. 80. With the $\frac{1}{4}$ -in. sand, 20 per cent limestone dust gave the best combination, and with the No. 10 sand, 10 per cent dust. With each aggregate, not only normal amounts of bitumen were tried but also amounts above and below normal; and 8.2 per cent bitumen for the coarse sand and 11 per cent for the fine were chosen as making the best possible mixtures, with the given aggregates, for use on a rigid concrete base. The cement in all cases was 55 penetration. It is evident from a comparison of the photographs of the blocks that the $\frac{1}{4}$ -in. sand gives mixtures less susceptible to temperature changes than the No. 10 sand and, when the individual blocks are studied and considered together with the number of blows in each case, the deduction must be drawn that the $\frac{1}{4}$ -in. sand is the better. This does not mean, however, that all $\frac{1}{4}$ -in. sands are better for asphaltic mixtures than all No. 10 sands. The comparative worth of any two sands, irrespective of tests made of other sands,

should be determined by separate tests made on the two sands in question.

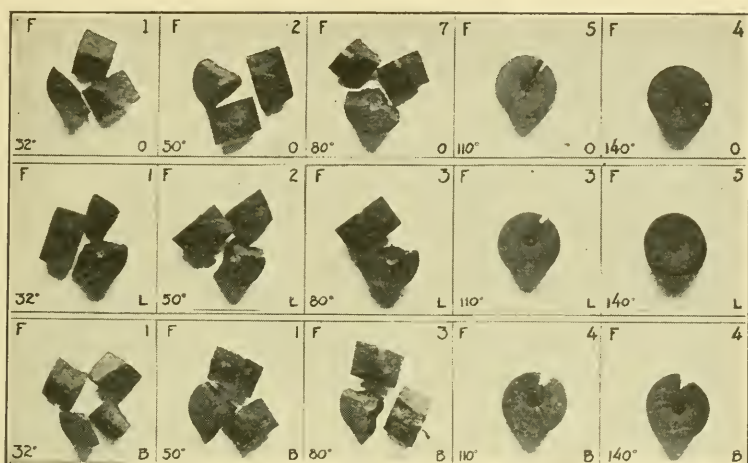


FIG. 159.—Different asphalt cements with fine sand. O, residual oil; L, lake asphalt; B, blown petroleum. Temperatures recorded in lower left corners; number of blows, upper right. Eleven per cent bitumen used in each case.

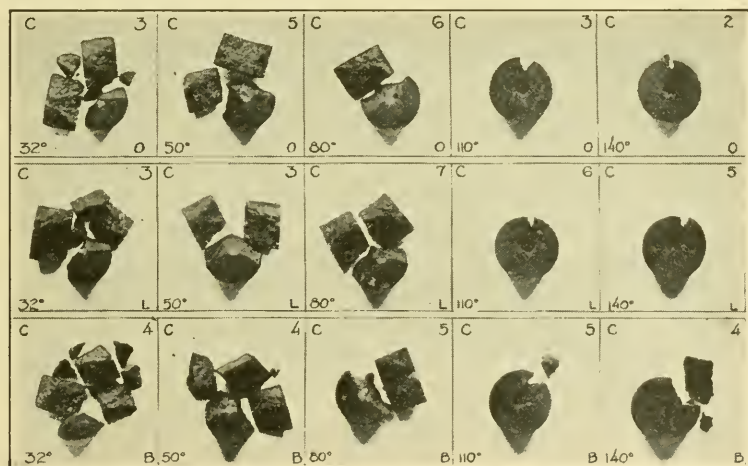


FIG. 160.—Different asphalt cements with coarse sand. O, residual oil; L, lake asphalt; B, blown petroleum. Temperatures recorded in lower left corners; number of blows, upper right. Eight and two tenths per cent bitumen used in each case.

302. Various Bituminous Cements.—It may be noted that with each of the sands represented by Figs. 159 and 160, three

different asphalt cements were used. There are many varieties of bituminous cements, differing either because of origin, manufacture, or treatment subsequent to manufacture. The *O* series of blocks represent a common residual oil product, and the *L* series a solid lake asphalt made into a cement by the addition of a residuum. Series *B* contains a blown petroleum of fairly high ductility. While changing the nature of the cement, as indicated by these three series of blocks, may change the results obtained, it is seen that a far greater effect is obtainable through changing aggregates.

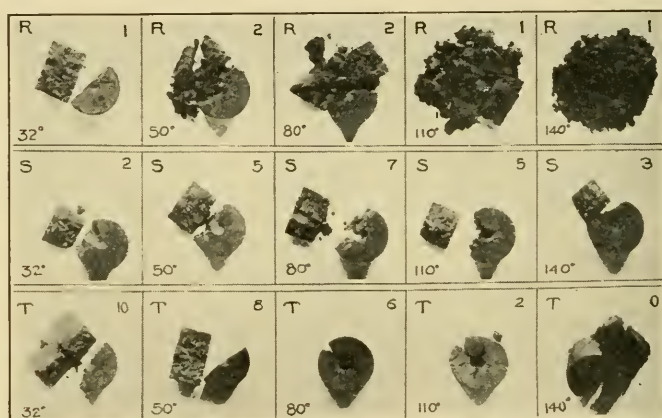


FIG. 161.—Tests of special mixtures. *R*, natural rock asphalt; *S*, coarse sand with a sulphurized bitumen; *T*, coarse sand with a heavy tar. Number of blows recorded in upper right corners, temperatures in lower left.

In Fig. 161, the material in the *R* blocks is known as "Rock Asphalt," being an impregnated sandstone mined from a land deposit. In mixing the series *S* blocks a compound of sulfur was added, while in the *T* blocks a high-carbon tar cement was used.

The mixtures represented in Figs. 159, 160 and 161, have at one time or another all been used to fulfill identical conditions and, therefore, their different behavior under the block test is of particular interest. It is seen that at high temperatures the *R* and *T* mixtures are distinctly inferior to those of the other four series. This does not mean, however, that there may not be rock asphalts other than the one illustrated that would give better results, nor does it mean that it is impossible to produce tar mixtures giving better results. Sets of blocks as contained in the other four series are important in that the engineer often has to

decide whether one product is more suited to his purpose than another, or he may have to decide on granting a price differential or royalty in favor of a particular product as to the worth of which extravagant claims may have been made.

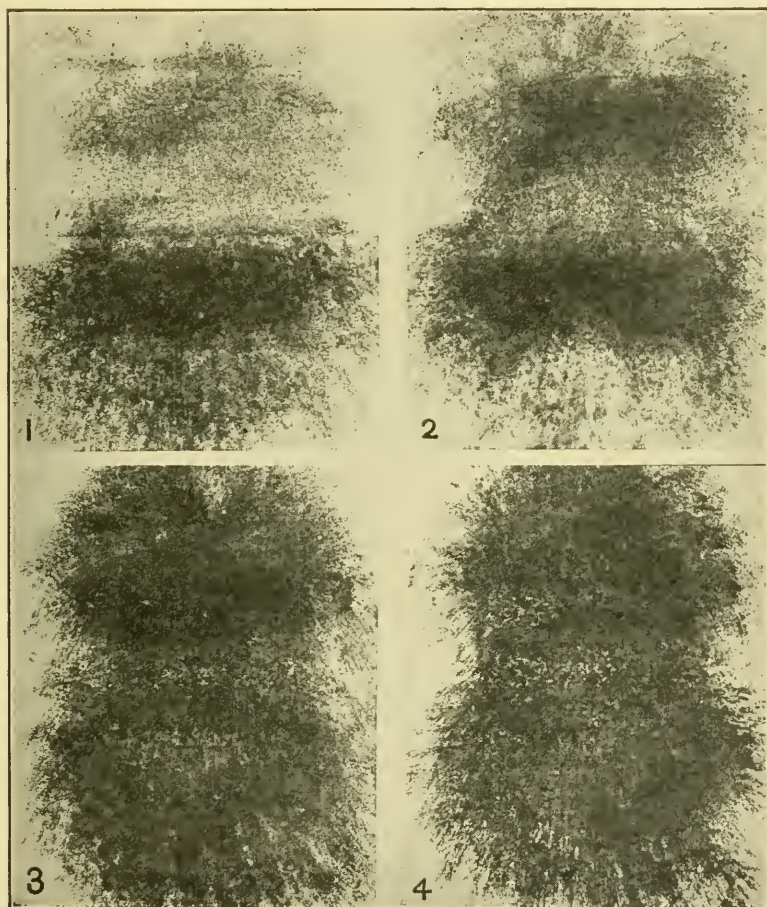


FIG. 162.—Pat tests of a mixture containing a soft bituminous cement used with a coarse sand. The correct amount of bitumen is represented by a stain midway of Nos. 2 and 3.

Detail data relative to the bituminous materials used in the mixtures illustrated are not given herein because misleading deductions might be drawn therefrom. It must be remembered that a pavement mixture is affected by the amount of cement and its penetration, and by the aggregate, including its filler; and

changes in any one of these elements might so change the mixtures illustrated as to alter the results radically. It is for the investigator, having at hand all his imposed conditions, to carry out the Block Test in accordance therewith, and from the results, to make his own decision in each particular case.

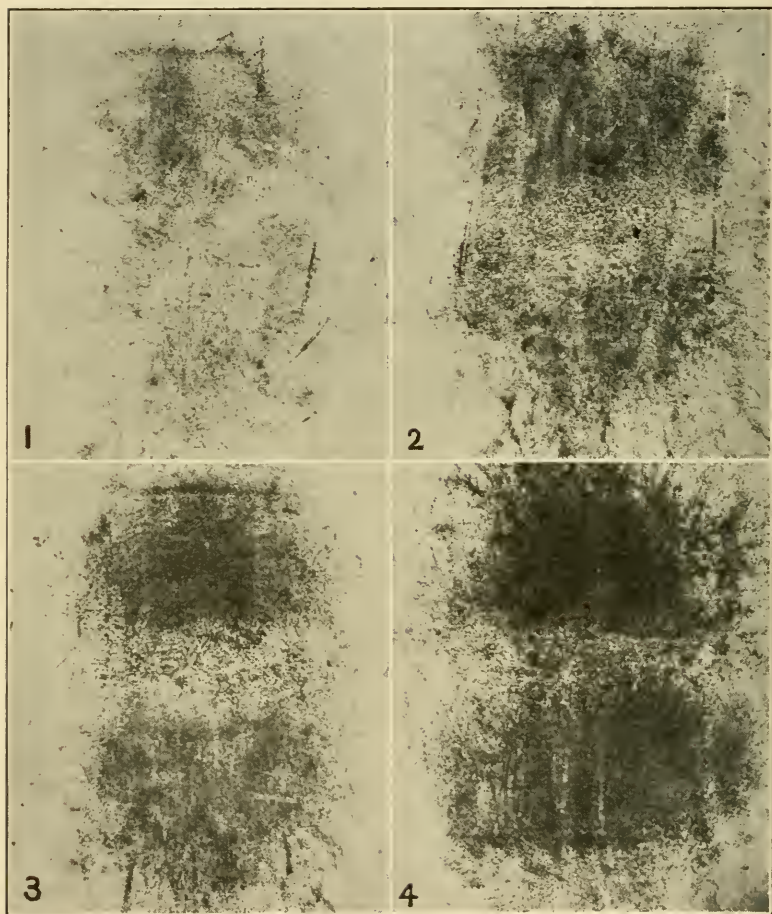


FIG. 163.—Pat tests representing a hard cement mixed with a fine sand. The correct amount of bitumen lies between stains Nos. 2 and 3.

303. The Pat Test.—Richardson's pat test, through comparison of the stains made upon paper by hot pats, has often been used for determining whether or not mixtures contain proper amounts of bitumen. To make the test, a sample, about 4 in. in

diameter, of hot mixture is dropped upon a piece of brown manila paper having a fairly smooth surface. The paper should be 10 or 12 in. square, creased down the middle and opened out on a firm wooden table—stone or metal conducts heat too rapidly. After doubling half the paper over the sample, the mixture is pressed down with a piece of wood until the surface is flat. It is then struck five or six sharp blows with the block of wood until the pat is about $\frac{1}{2}$ in. thick.

Characteristic pat papers are shown in Fig. 162 and 163. In each figure four stains are reproduced, the amount of bitumen ranging from a minimum to a maximum with the normal amount lying between the second and third stain in each case. These two sets of papers are shown in order to illustrate that, under different conditions, the normal amount of bitumen is represented by different stains. The character of the stain depends not only upon the quantity of bitumen, but also upon its origin, upon the nature of the aggregate and upon the temperature at which the pat is made. The test is like the slump test for portland cement concrete, in that having once fixed upon a proper "consistency," through practical experience or otherwise, this consistency can be maintained constant by means of the test as long as the characteristics of the ingredients are not changed.

304. Action of Water on Mixtures.—All bitumens are more or less acted upon by water under certain conditions, and the deterioration that may take place in bituminous pavements due to moisture has always been the subject of a great deal of discussion. In Table XXXVIII, data are given pertaining to a test which gives an indication of the action of water. Two sets of blocks, for use in the "Block Test" (previously described in the present chapter) were made; one set with fine sand as the aggregate, the other with coarse sand. With each sand the six different bituminous cements shown in the table were used. The blocks were stored in water, maintained constantly at 120°F. and after a maximum storage of 234 days those made with Trinidad were the only ones showing significant water action. The surface of these blocks could easily be scraped with a thumb nail to a depth of $\frac{1}{8}$ to $\frac{3}{16}$ in. Notwithstanding this evident surface deterioration, of all the blocks, the Trinidad ones showed by far the least effect of the water storage when they were broken in the Block Test. The table contains data for breaks at 80°F. only, and it may be seen that the number of blows decreased in variable

amounts for the different mixtures as the length of water storage was increased. This was true also for breaks at the other temperatures used in the Block Test; except at 32°F., the breaks at this temperature after the maximum water storage being one blow for all mixtures.

TABLE XXXVIII

Cement	Aggregate	Bitumen, per cent	No days in water; number of blows	36 days in water; number of blows	98 days in water; number of blows	234 days in water; number of blows	Visible action of water on surface of blocks
Bermudez	Fine.....	11.0	4	2	1	1	Insignificant
	Coarse.....	6.5	4	3	2	1	Insignificant
Trinidad	Fine.....	11.0	5	5	4	4	Extensive
	Coarse.....	6.5	6	5	5	4	Extensive
Karnaek	Fine.....	11.0	4	3	2	1	Insignificant
	Coarse.....	6.5	4	3	3	2	Insignificant
Tarvia X	Fine.....	11.0	8	4	2	1	None
	Coarse.....	6.5	10	4	1	1	None
Standard	Fine.....	11.0	5	5	4	2	Insignificant
	Coarse.....	6.5	6	6	3	1	Insignificant
Willite	Fine.....	11.0	6	6	3	3	Insignificant
	Coarse.....	6.5	7	6	4	2	Insignificant

It is evident from this water test that bituminous mixtures may deteriorate under the action of water, but laboratory deterioration cannot be taken as a measure of their probable behavior on the street. In properly constructed pavements, water has but little opportunity to attack the ingredients of which the wearing surface is constructed and accordingly there are many very old pavements which show no deterioration traceable to the action of water. One of the outstanding points of the water test just described is that Trinidad, well known for its disintegration in the laboratory as a cement, when exposed to the action of water, showed up best of all as a paving mixture. Again a word of caution about interpreting tests of bituminous mixtures; the relative standing of the various cements shown in the water-test table might easily be reversed if other aggregates and other bitumen percentages were used.

CHAPTER XVII

PLANT AND CONSTRUCTION

305. Plant.—As with concrete mixers so with plant for the hot mixing of bituminous mixtures there is a large variety of good equipment on the market manufactured by different concerns. The several units which make up a plant, combined on rather an extensive scale, are illustrated in Fig. 164. A layout of this magnitude represents a large investment and should be under-taken only after first hand investigation including inspection of existing plants.

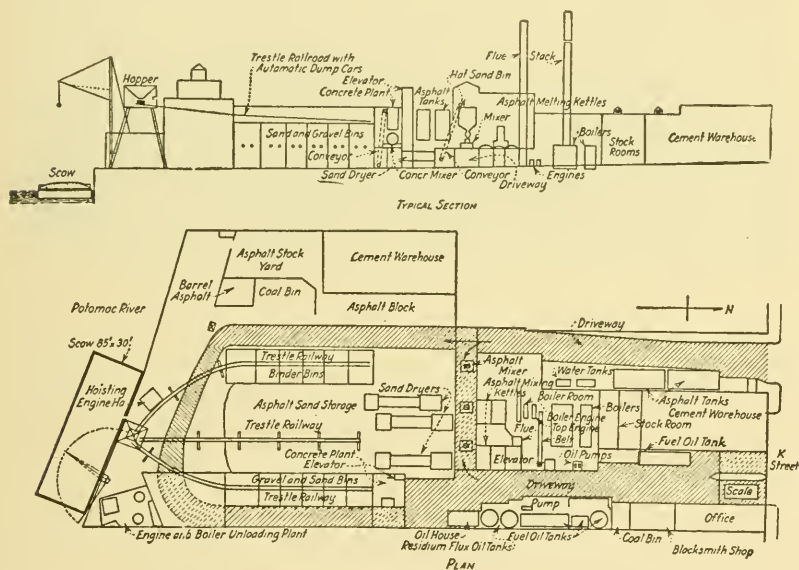


FIG. 164.—Plant of a Washington, D. C. contractor.

Early in 1921, Philadelphia placed into operation at an initial cost of \$110,000 a duplex plant, each half consisting of a twin pug-mill mixer of 12-cu. ft. capacity together with the necessary weighing devices, dryers, heating kettles, storage, etc. A 100-hp. boiler is used for heating steam coils, and for operating the oil and other pumps, while a 125-hp. electric motor furnishes power for the dryers, mixers, sand elevators, etc. Fuel oil burners are used

under the drums of the dryers and the hot gases are drawn through the drums by means of exhaust fans.

306. Semi-portable Plants.—Semi-portable plants are arranged in units for convenient transportation but, nevertheless, designed

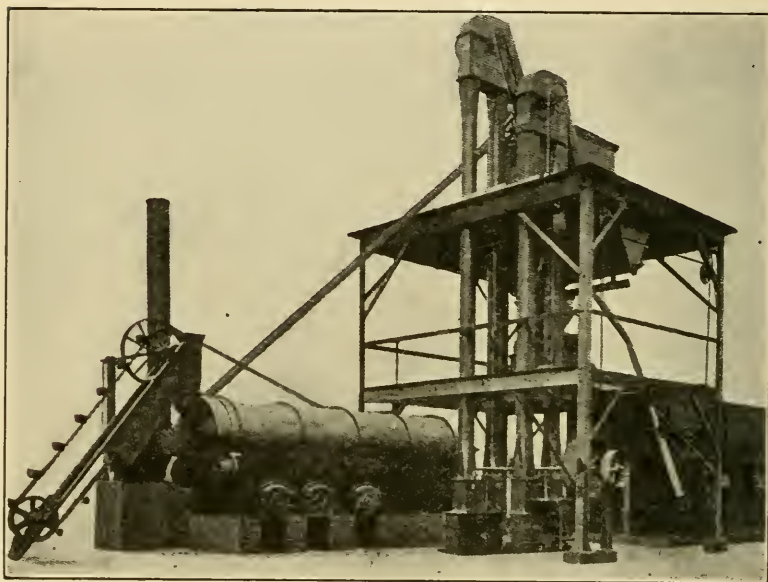


FIG. 165.—Semi-portable plant.

to rest on masonry foundations as illustrated in Fig. 165. This type of plant is obtainable usually in sizes ranging from 6 to 12 cu. ft. or even 15-cu. ft. mixer capacity. In order that the

TABLE XXXIX

	6-cu. ft. mixer	9-cu. ft. mixer	12-cu. ft. mixer
Dryer, ton per hour.....	6	9	16
Asphalt kettles.....	Two 7½-ton	Three 7½-ton	Three 11-ton
Hot sand storage, ton....	6	9	16
Weighing box and scales, cubic feet.....	7	10	15
Asphalt bucket and scales, cubic feet.....	2	2½	3
Power, horsepower.....	20	30	40
Boiler, horsepower.....	40	50	60

mixers may operate continuously other items of the plant should have capacities approximately as shown in Table XXXIX.

If, instead of using steam for melting the asphalt, fire melting kettles are used, the boiler horsepower may be reduced about 25 per cent. Oil burners are generally used for the dryers. A roughly estimated cost (1922) of a 6-cu. ft. plant completely installed is \$12,000, of a 9-cu. ft. plant, \$18,000, and of a 12-cu. ft. \$24,000.

307. Portable Plants.—Portable plants similar to that shown in Fig. 166, may be obtained in all sizes up to and including 12-cu. ft. mixer capacity. Except for their supports they do not differ

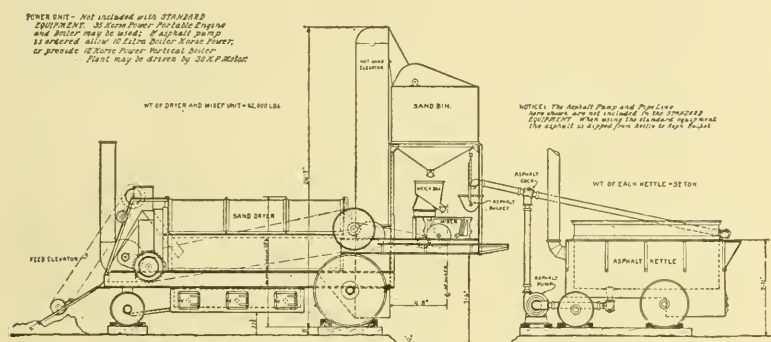


FIG. 166.—Portable plant with 9-cu. ft. pug mill mixer.

materially from those just described for installation on masonry foundations, but cost from \$1,000 to \$2,000 more for equivalent capacity. However, it is possible to buy plant for less money by cutting down, at the expense of capacity, the size of the dryer and eliminating the sand storage. Plant set on masonry at a city's sand supply usually proves to be the most economical, permitting efficient installation of labor saving devices, and saving the cost of wheels, axles, etc. Nine- and twelve-cubic foot plants are sometimes installed on railroad cars, in which case the shipping weight is about twice that of an equivalent plant for operation on masonry foundations.

There are also miscellaneous types of portable plant. One type consists simply of a wagon in which the aggregate is heated in a metal bin provided with fire tubes, the bituminous material in another compartment, and the mixing is done by hand with shovels, on a metal platform let down from the rear of the wagon.

Other types are but converted concrete mixers provided with heating appliances.

The type illustrated in Fig. 167, does good work. With a \$10,000 plant (1922 price) the output is 3,000 lb of hot mixture every 10 minutes. There is also a size at $\frac{2}{3}$ the price with about $\frac{2}{3}$ the capacity. In view of the variety of uses that may be found for a hot mixture (including its use in place of the great amount of inferior cold patch work now done on bituminous macadam), most communities can find work enough to justify a plant of at least this capacity.

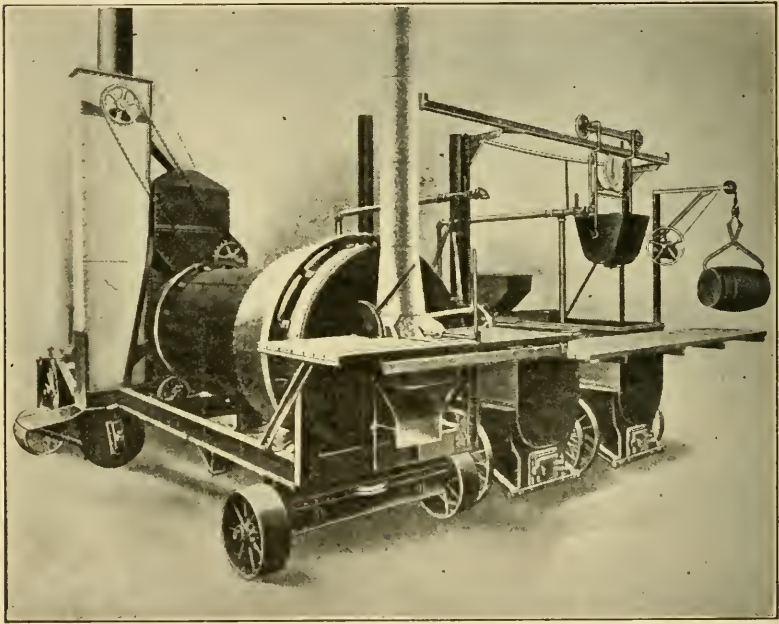


FIG. 167.—A portable plant with 3,000-lb. batch mixer of drum type.

308. Plant Capacity, Mixing and Costs.—As brought out under “Different Aggregates,” Chap. XVI, the weight of a given area of pavement depends upon the character of the aggregate and also upon the bulking effect of the bituminous material. When mixtures are controlled by the “Block Test” the weight per square yard of pavement per inch thickness is obtained from the specific gravities of the blocks; and, since mixer charging is usually on a weight basis, the plant capacity in square yards may be easily computed for each job.

The output of hot mixture depends almost entirely on the hot aggregate supply. Plant with pug-mill mixing units should be always provided with hot aggregate storage. The aggregate is fed into the drum continuously. If wet, it must be fed more slowly than when dry, and the capacity is largely cut down. Drying should start early in the morning so that the storage bin may be full of hot sand when mixing starts. Dust used for filler is not heated but is added to the other aggregate in the mill, after which it is well to give the mixer a few turns before adding the bituminous cement. Cold dust cools the aggregate and, therefore, the more dust the greater the heat that must be applied in the dryer. Also, the more the dust, the hotter the mixture must be for satisfactory handling on the street. Such factors tend to cut down rated output.

As an example, for an 800-lb. (8-cu. ft.) sand, 200-lb. dust mixture, with an 8-mile summer-time haul from the plant to the street, it was found that the sand had to be heated to 500°F. The sand and cold dust were mixed a few seconds, the asphalt added at 325°F., mixed 1 min., and the temperature of the resulting mixture was 400°F. Ten batches, or 11,000 lb., were carried per truck, and the temperature upon arrival on the job was 360°F. Care has to be exercised when dealing with high temperatures, but with asphalt having a flash point, as in this instance, above 480°F., and showing no deterioration, and no unreasonable hardening, when heated above that temperature for a long period, it is evident that good results can be obtained under the conditions just cited.

In the preceding example, a 10-batch truck load every 18 min. was the best time that could be made, and this with the latest improved automatic weighing devices and measuring boxes. Even with combinations containing less dust, ingredients should be mixed at least 1 min., and upon this basis an exceptionally well-trained crew seldom averages 40 batches per hour.

With the 3,000-lb. batch plant having mixing drum attached to the dryer, there is no hot-sand storage. It takes from 6 to 8 min. to dry and heat a batch of aggregate, and about 2 min. to discharge it into the mixing drum. The charge is mixed while the next batch of aggregate is being heated, and thus the output is 3,000-lb. of hot mixture every 8 to 10 min. In this type of plant, since it is difficult to make temperature readings, heating the aggregate cannot be regulated as readily as with the hot-sand storage type.

Plant charges have often been unreasonably large on account of excessive time spent in idleness. As set forth in a preceding chapter, concrete plant frequently work too few days in a year; this is even more generally true in the case of asphalt plants. Charges should be worked out as explained under the heading "Cost Keeping," Chap. II. Labor at the plant also has been a very variable factor, since it depends so much upon the facilities installed for handling the materials. As an example illustrating plant charges, consider a \$10,000 plant which worked 250 days per year with an average output per day sufficient for 800 sq. yd. of pavement 1 in. thick. Based on a yearly rental equal to 40 per cent of the original cost, plant charges amounted to 2 cts. per square yard 1 in. thick. If the plant had worked but 100 days this charge would have been 5 cts. As approximate averages, labor at the plant may be taken at 7 cts. and fuel at 2 cts. per square yard 1 in. thick.

309. Loss of Dust.—Clouds of dust about a plant mean, first of all, that valuable material is being lost and that the resulting mixture, containing less than the proper amount of dust, will not meet specifications. Then often, other businesses in the neighborhood may be of such character that the dust becomes a nuisance and results in an injunction closing down the plant. The dryer should be dust tight, also the hot material elevators, hot storage bin, etc. With plant designed so as to require an exhaust fan to pull the hot gases through the dryer there is always much dust forced into the stack. Where the dust used for filler is mixed with the aggregate in the dryer the situation is likely to be more difficult to handle than where the dust is added in a pug mill. A shed about the plant keeping out wind helps to cut down the dust nuisance.

310. Transportation.—The problem of transporting hot mixtures is in many respects like that of handling wet concrete, though not so difficult. There are three main time factors: Time at the mixer waiting for load; time on the road; and time unloading on the street. From the standpoint of economy a decision has to be made as to the size of truck to use. The maximum length of haul is determined by the fact that the material must be hot upon arrival on the job.

For new construction, large trucks, 5 to 7½ ton, are economical. Ordinary hoist bodies with not less than 45 deg. dumping angle are satisfactory for practically all mixtures. With a 9-cu.

ft. mixer turning out a 1,100-lb. batch every $1\frac{1}{2}$ min., 15 to 20 min. is consumed in loading a truck with 11,000 lb.; and not more than 15 min. should be permitted for unloading on the street. As an example of the cost per square yard for transportation, data were kept on a job with an 8-mile haul. A fleet of trucks was used, each carrying 11,000 lb. and costing \$25 per day. An average of 3.6 round trips per truck was made daily, the cost, therefore, being \$7 per trip; that is, 7 cts. per square yard 1 in. thick.

For repair work smaller trucks are necessary since considerable time is taken up in moving from patch to patch. Even in warm weather and leaving the plant with as much heat as is safe, material should be rolled in place in less than 2 hr. after mixing.

311. Spreading the Mixture.—Spreading operations and truck arrivals need close coordinating. While it is expensive business



FIG. 168.—Spreading the hot mixture. Note the use of a guide board or "screed," in order to control the thickness of loose material.

keeping a loaded truck standing idle on the job waiting for the spreading gang, it is still more wasteful to hold the latter idle awaiting the arrival of a truck. Care should be taken to dump the hot mixture into small piles, as illustrated in Fig. 168, spaced according to the area to be covered so that none has to be handled over much distance. The laborers should not be permitted to stand or step on any of the loose mixture.

A good size for a spreading gang is four shovelers and two rakers, and these men should empty the trucks as well as spread the mixture. If the spreaders are behind in their work, hot

material should not be dumped far in advance of the time that it can be handled by the spreading gang since then it cools and the progress of the work is further retarded. A good plan is to have two gangs, one on each side of the roadway, trucks arriving every 17 to 18 min., taking 15 min. to unload, and allowing 35 min. per gang for spreading. This alternates the gangs to some extent and gives a little time for resting, changing for hot tools, etc. On this basis a gang will spread the equivalent of 1,370 sq. yd. of pavement 1 in. thick per 8-hr. day. With a gang cost per day of \$26 this gives a cost of less than 2 cts. per square yard 1 in. thick. However, due to truck breakdowns or other mishaps or items of mismanagement, it is seldom that as good an average as 3 cts. is attained.

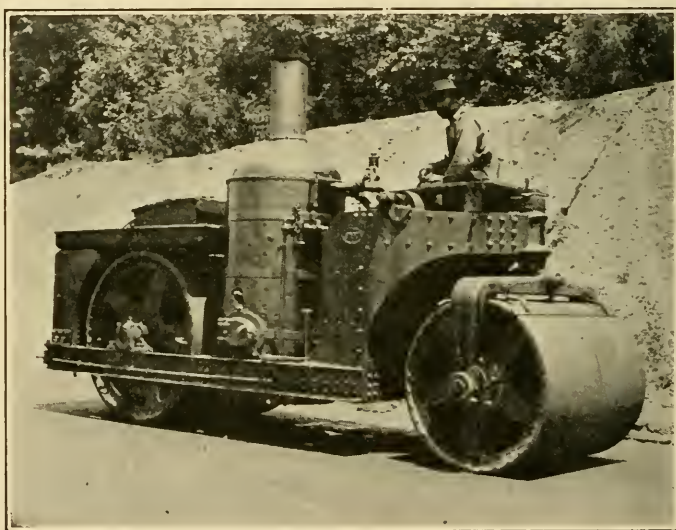


FIG. 169.—Eight-ton Tandem roller.

312. Surface Finishing.—Tandem rollers are best for rolling the hot mixture, though good results can be obtained with a three-wheel roller. In addition to having a large roller, about 8 or 10 tons, as illustrated in Fig. 169, it is well to use a small 2 or 3-ton one, though this is not absolutely necessary. The small roller can get on the hot surface quickly after spreading and give it an initial compression, while the larger roller can follow up with the final compression, ironing out the slight tracks left by the first rolling. Much ado is often made about the manner of rolling,

using such terms as, longitudinal, transverse, and diagonal, but if the hot mixture is uniformly spread, a little judgment in rolling



FIG. 170.—Tamping the edges along the gutters.



FIG. 171.—Smoothing iron, used for ironing out joints and spots that cannot be reached by the roller.

will give a good smooth surface. Poor results, more often than not, come from a roller which rocks from side to side either

because it is worn out or because its center of gravity is too high. Most specifications limit the work with a single large roller working continuously to about 200 sq. yd. per hour. With a charge of \$1.50 per hour, including operator, this gives \$0.0075 (three-quarters of a cent) per square yard. In addition to rolling, two tampers are generally required for compressing the mixture along the edges, around manholes, etc., as illustrated in Fig. 170. Also a smoothing iron, as illustrated in Fig. 171, is used for ironing out joints or spots that cannot be reached by the roller. For tamping and smoothing, a charge of 0.75 cts. is necessary, which, added to 0.75 cts. for rolling, gives 1.5 cts. for surface finishing. Some specifications require that the surface be dusted with cement or limestone dust but this is not necessary.

313. Recapitulation of Cost.—For a surface $1\frac{1}{2}$ in. in thickness, costs may be tabulated as follows; that for materials, of course, depending greatly upon local conditions, while the other costs should fluctuate to a much less degree.

Sand.....	@ \$ 0.80 ton, 120 lb. =	\$0.048	
Dust.....	@ 5.00 ton, 30 lb. =	0.075	
Asphalt.....	@ 15.00 ton, 15 lb. =	0.113	
Total for materials.....			\$0.236
Plant charges @ 100 days per year.....		0.075	
Labor at the plant.....		0.090	
Fuel.....		0.030	
Total at the plant.....			0.195
Transportation @ \$9 per ton.....			0.075
Spreading the mixture.....			0.045
Surface finishing.....			0.015
Total for operating.....			\$0.566
10 per cent foremen and over-head.....			0.057
10 per cent contingencies.....			0.057
15 per cent contractor's profit.....			0.085
Estimated bid price.....			\$0.77

314. Bituminous Patching.—For surfaces that have been constructed by the hot-mix method there is but one method of repair; that using hot mixture for patching, though, of course, as a makeshift to meet an emergency, mixtures made with bituminous materials that have been liquified by the addition of volatile cut-backs may be used. These makeshift patches will, however,

early prove to be much below the quality of the surrounding surface and will soon have to be replaced.

As has been previously stated there are small mixers on the market well adapted to the needs of small communities. Moreover, the mixer should be used not only for the repair of those pavements that have been constructed by the hot-mix method but also should take care of both surface treated macadam roadways and penetration macadam. Work of this character is illustrated in Fig. 172. The hot mixture can be proportioned exactly in accordance with the desires of the engineer. Cold



FIG. 172.—Placing skin patches of hot material on an old surface treated macadam road. Many of these patches are but $\frac{1}{4}$ to $\frac{1}{2}$ in. in thickness.

patches have to be mixed more by rough rule-of-thumb methods, and give less satisfactory results. For cold patch work the aggregates used are generally more expensive than the sand that can be used for hot mixtures. Also the cost of the bituminous material used is, under ordinary conditions, greater for cold patching, while labor costs are about equal. The life of a hot-mix patch greatly exceeds that of a cold one.

Figure 173, illustrates hot-mix patches that were used in order to smooth up an old trap rock block roadway. This work cost but 60 cts. per square yard of patch in place, and, though not very sightly, it was a very welcome improvement.

Several labor saving methods have been tried on asphalt pavements for cutting out patches. Ten machines such as that illus-

trated in Fig. 174, were used by The Rock Asphalt & Construction Corporation of Buffalo, N. Y., during one working season, and 200,000 sq. yd. of patching were accomplished, that is at the rate of about 200 sq. yd. per machine, per 8-hr. day. The machines are self-propelled and each is operated by one man. The heavy weight fitted with a chisel point chops through the asphaltic surface, thus outlining this spot to be repaired with a deep cut. A gang of pickers later comes along and digs out the asphalt.



FIG. 173.—A hot bituminous mixture used for smoothing up an old stone block roadway.

Figure 175, is a photograph of a patching gang using a portable air compressor operating two drills of the jack-hammer type equipped with 3-in. chisel-edge bits. While machines invariably save labor, nevertheless plant charges may be so high that it will be more economical to use hand methods. The outfit shown in Fig. 175, was directly compared with a gang using hand picks, operating side by side on jobs of different degrees of difficulty. Working on a thin surface, about 1 in. in thickness and composed of a dry friable mixture, one man can pick out, so that

it can be handled with shovels, about 5 sq. yd. per hour. With wages at 45 cts. per hour, this gives 9 cts. per square yard. Any charge for tools is practically negligible. On a tough surface,

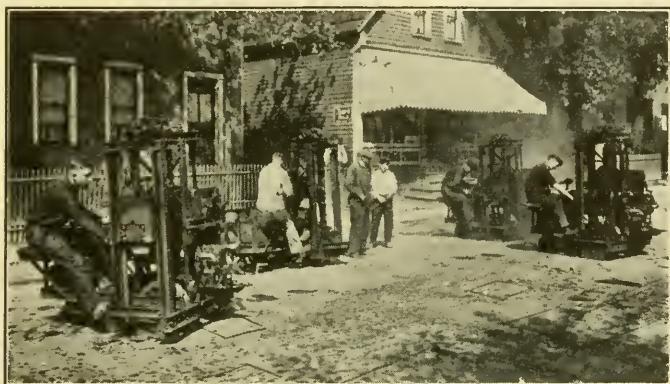


FIG. 174.—Chopping machines as used by the Rock Asphalt and Construction Corporation, Buffalo, N. Y.

3 in. in thickness, one man may cut out as little as $1\frac{1}{2}$ sq. yd. per hour, or at the rate of 30 cts. per square yard.



FIG. 175.—Cutting asphalt pavement with a portable air compressor using 60-lb. jack hammers. Most work of this character may be done more economically by hand picking.

An air-drill outfit for cutting patches must have mobility and accordingly should either be mounted on a motor chassis or be animal drawn. An outfit operating two drills would cost approxi-

mately \$4,000. Based on 250 days work per year and a life of 5 years, plant charges per year may be taken at \$8 per 8-hr. day. An operator costs \$4 per day, two drillers \$8 per day and fuel and oil about \$4 per day, making a total of \$24 per day or \$3 per hour. On a thin easily broken surface, 18 sq. yd. may be cut per hour at a cost of $16\frac{2}{3}$ cts. per square yard; on a 3-in. tough surface 10 sq. yd. per hour, at a cost of 30 cts. per square yard. Thus on average surfaces it may be said that hand picking is more economical than air drilling, the economy being greater on less difficult work and smaller on that more difficult. On exception-



FIG. 176.—A bituminous pavement 14 in. thick. On difficult cutting of this nature the use of air drills is more economical than hand picking.

ally hard cutting, as for instance in the case of the 14-in. bituminous pavement illustrated in Fig. 176, the air drills show material economy. Hand methods on this job, including shovelling the material from the cut as work progressed, cost \$5 per square yard. With air drills the cost was \$1 per square yard.

315. Use of Salvaged Asphaltic Mixtures.—Several different ways have been used in making over material salvaged from asphalt roadways in order to utilize it for patching. One method is to heat the old material in a portable drum mixer on the street and then to tamp it back into the roadway from which it was cut. By the steaming method, broken up asphalt is placed in kettles at a central yard, along with considerable water,

and boiled for several hours until all the water is evaporated. During the boiling the mixture is spaded and stirred with large hand bars, and, when finished, is handled in the same manner as new mixtures. The method used to the greatest extent is to run the old material, broken to $1\frac{1}{4}$ -in. size, through the portable type of plant (material dryer with drum mixer attached) previously described in the present chapter. New ingredients are combined with the old in proportions about as follows: 1,500 lb. old material, 825 lb. sand, 75 lb. limestone dust, and 110 lb. asphalt cement.

The use of old material is doubtful economy on account of the labor necessary for handling it. Generally it is cheaper to purchase new ingredients. Reclaiming old material simply by heating and mixing puts back into the pavement that which has just been removed because of its poor behavior. When an attempt is made to rejuvenate old material, obtained from a number of different sources, by the addition of new sand and asphalt, the combined proportions of the ingredients making up the resulting mixture are indefinite; one batch may correspond to what has been classified in the "Design of Mixtures," Chap. XVI, as a "cracked" surface while the next may correspond to a "waved" one. Pavements of properly designed mixtures can, throughout a satisfactory service of many years, be patched again and again until the majority of the surface is composed of patches; but this can be accomplished only if the very best materials are used for these repairs.

PART V
BLOCK SURFACES, STONE CURB, TREES

CHAPTER XVIII

GENERAL DATA FOR BLOCK SURFACES

316. Scope.—Prior to giving detailed specifications of the various types of blocks used for pavements, data of a general nature will assist an understanding of the subject of block surfaces. Subsequent chapters give detailed information pertaining to stone blocks, paving bricks, wood blocks and asphalt blocks. Before the fine grading of the roadway is finished paving blocks should be hauled and placed beyond the curb lines in quantity sufficient for the proposed work. They should be handled carefully, so as not to be chipped or broken, piled neatly, and kept clean. Wood blocks should be laid as soon as practicable after treatment, and while stored on the job should be protected from the sun and exposure to the weather.

317. Cushion Layers.—The word “cushion” has long been used for the layer of sand or other material placed on the pavement base and in which the surface blocks are firmly bedded. From this choice of words it is not to be assumed that the bed of sand or other material is used in order to give resiliency to the pavement. Its purpose is to even up the base and to compensate for variations in the depth of the blocks. The thinnest layer of cushion which allows smooth paving and firm bedding is the best, and in no case, with new block, should a layer of much more than 1 in. be necessary. Stone blocks, Durax in particular, require the maximum thickness of cushion while other types require less, usually not more than $\frac{1}{2}$ in. At times other means than a cushion layer are used for obtaining a smooth surface, for instance, vitrified blocks have been bedded true to grade while the concrete of the base was still green; and as another instance, wood blocks are often laid directly on a smooth base with only a bituminous paint coat intervening.

Bituminous mixtures, on the order of sheet asphalt, laid between 1 and 2 in. in thickness, and even as much as 4 in. between the base and the block surface, have been used as cushion layers. Bituminous mixtures are relatively so very

expensive that it is difficult to justify them for use as cushion layers. A $1\frac{1}{2}$ or 2-in. bituminous layer is in itself a good wearing surface, and covering it with blocks would seem to be extravagance.

318. Sand Cushion.—The original cushion for block pavements was plain sand. It was used in very thick layers and generally joints between the block were sanded only. Much trouble was had because in spots the sand washed out or moved from under the block while in other spots it bunched up to several times its initial thickness. In the modern pavement, using bituminous filler and a thin cushion layer, these troubles have not been experienced. Sand passing a $\frac{1}{4}$ -in. screen and satisfactory for concrete is suitable for a cushion. Generally up to 8 per cent loam, clay or silt is not considered objectionable. The sand bed is shaped to the correct cross-section by means of templets riding either on the curbs or on screed timbers. In some localities the sand is rolled with a light hand roller prior to shaping, in others the rolling is omitted.

319. Cement-sand Cushion.—With development of the grouted joint and monolithic pavement of some years past the cement-sand cushion came into vogue. Any $\frac{1}{4}$ -in. concrete sand is satisfactory for a cement-sand cushion, and generally the proportions used are 1 cement: 3 sand, and in no case leaner than 1: 4. The bed is shaped as when using sand alone. Some engineers mix water with the sand and add cement, making a mealy mixture that can be easily raked; others sprinkle the cushion just prior to laying the block. It may be questioned whether the extra cost of adding cement to the sand is justified when a bituminous filler is used for the joints.

320. Paint Coat Bed.—Bituminous cement such as used for joint filler is also satisfactory for a paint coat bed. It is applied hot, either by mopping with a roofer's string mop, by means of a sprayer, or by using a rubber or iron squeegee, the last method being in most general use. To date, the paint coat has practically been limited to wood-block construction and is applied not more than $\frac{1}{8}$ in. in thickness, which is thick enough because the base, when using this design, must be brought to a smooth true surface equal to that obtained in one course roadway construction, and the tolerance permitted for the depth of wood block is but $\frac{1}{16}$ in. plus or minus the specified depth. Advocates of the paint coat claim it ties the wood block to the base. They further

claim that it does away with a relatively thick cushion containing sand and thereby eliminates the possibility of long continued moisture between the base and the blocks causing undue deterioration.

The blocks are laid on the paint coat as soon as it has cooled slightly (under normal conditions within $\frac{1}{2}$ hr.), and then rolled with a tandem roller weighing from 5 to 8 tons.

321. Laying the Courses.—In general, blocks should be laid in parallel straight courses from curb to curb. Durax pavement is a



FIG. 177.—Laying Durax in concentric arcs.

frequent exception, and there are a few exceptional conditions to be met in the case of other surfaces. Durax blocks instead of being laid in straight courses, are often laid, as illustrated in Fig. 177, in circular concentric arcs with the largest blocks at the center of the arc and the smaller ones at the springing line. The radii of the arcs may be varied from 3 to 7 ft.

When blocks are placed in straight courses they are usually laid at right angles to the longitudinal axis of the street, except that wood blocks are often laid in straight diagonal courses generally at an angle of from 60 to 70 deg. to the curb. All joints should be broken, with wood block, a lap of at least $2\frac{1}{2}$ in.; and with other types of block which are longer, a lap of at least 3 in.

Around curves blocks may be laid in accordance with one of the three methods suggested in the brick specifications of the American Society for Municipal Improvements. Methods Nos. 1 and 3 are shown in Fig. 178, and No. 2 in Fig. 179. For Method No. 1, distance measured along the curb on the outside of the curve from the P. C. to the P. T. should not be more than 13 per cent greater than the corresponding distance on the inside of the curve. The radius of the outer curb line should not be more than 13 per cent greater than the radius of the inner curb line.

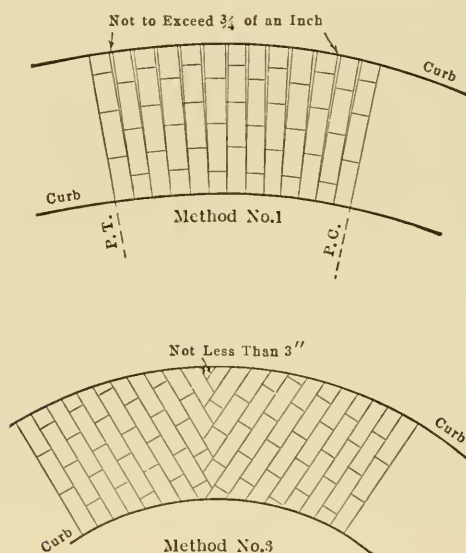


FIG. 178.—Two of the three methods suggested by American Society for Municipal Improvements for laying brick around curves.

Method No. 2, Fig. 179 may be used where the curvature and width of the street will not permit Method No. 1. Block should not be broken longitudinally to make closure, and in no case should the space to be battled in, at right angles to the courses, exceed a whole block. If Method No. 1 cannot be used and No. 2 is not desirable, Method No. 3, Fig. 178 may be adopted. In all methods, except as noted, nothing less than one-half block should be used in making closures.

The brick in the photograph, Fig. 179, are hillside, repressed, with lugs. Hillside wire cut, with wire cut lugs, having their non-skid grooves or depressions transversely across the brick, are laid with

the length of the brick parallel to the curb instead of cross-wise of the roadway. These brick, accordingly, require no special methods around curves but are laid in the same manner as on straight pavements, except that the courses, being parallel to the curb, are curved. (This type is no longer a Department of Commerce "recognized type" see Chap. XX.)



FIG. 179.—An example of paving around curves with method No. 2, American Society for Municipal Improvements, no bat being less than 3 in. The brick are hillside, repressed with lugs. (*Courtesy of the Paving Brick Assn.*)

322. Bedding the Blocks.—With all types of blocks, except stone, the depth runs with such uniformity that once the cushion has been struck off parallel to the finished surface, little effort is required to lay the blocks true to grade. With stone block it is necessary for the paver to make a separate bed for every block. Pavers usually conform to the approved grade by using lines, stretching from the surface already laid, to fixed points ahead, which lines may be noticed in Fig. 177. Care must be exercised not to crowd the grade lines in the slack as that produces a pavement in a series of waves. While laying the blocks the pavers should not walk or stand on the cushion, all paving being done from blocks already laid. Following the placing of the blocks,

they should be inspected, culled and approved for ramming or rolling.

Stone blocks must be rammed individually to a solid bearing. (Rolling does not produce good results as it does not bed the shallower blocks properly.) Those blocks which ram below the finished grade of the pavement must be removed with paving tongs, an added amount of cushion material supplied and then again rammed to a true surface. Other types of blocks, after they are placed, are bedded by rolling, first parallel with and then diagonally to the curb until the surface becomes smooth and true to the proper contour. With mortar beds, rolling should be completed before the mortar sets. In areas that cannot be reached by the roller the blocks should be tamped with a hand tamper applied upon a 2-in. plank. Rollers should not be excessively heavy because then large numbers of blocks are broken. In any case, all blocks injured during rolling should be replaced. Tandem rollers are usually specified, 3 to 5 tons in weight. Generally the pavements, after rolling, are tested with a 10-ft. straight edge laid parallel with the curb and any depressions in excess of $\frac{1}{4}$ in. are corrected by relaying the blocks.

323. Filling the Joints.—Proper filling of the joints in a block pavement keeps the blocks stable, and preserves the edges of the blocks so that they do not become worn or cobbled by traffic. Whenever the material wears down below the surface of the blocks the joints should be refilled in order to prevent cobbling. The method which has been widely favored in recent years of setting lugless brick with tight joints, meets with some criticism on the basis that it is not possible to fill every joint with liquid bituminous filler even at very high temperature. If joints can be made so tight that they cannot be filled there would appear to be no cause for worry as long as stability is obtained, cobbling is prevented and satisfactory service is rendered. Until actual records appear of failure on the road, the bituminous filled close joint brick pavement must be accepted as being equal to that having wide joints.

324. Bituminous Filler Specifications.—For tight joints, as in the case of lugless vitrified brick, and wood block, bituminous cement alone is used; for wider joints as in the case of granite block a mastic consisting of cement and sand is made, or the joints are first partially filled with coarse sand, pebbles or stone grits and the cement then poured. Tar products and asphalts for

mastic fillers can be compared by studying results obtained with the Block Test as outlined in Chap. XVI. For cement fillers, tars are softer in summer and harder in winter than asphalts. On the hypothesis that tar cement is more adhesive than asphalt, it is favored by some engineers; in which case, to reduce the susceptibility to temperature changes, often a tar cement is mixed with asphalt, about five parts of the former to one of the latter. While there is some difference of opinion as to bituminous fillers the tendency today is strongly toward asphalt as being more satisfactory than tar pitch. Oxidized asphalts have higher melting points than steam refined ones of the same penetration, depending largely upon the extent to which the asphalt has been blown; and accordingly, oxidized fillers are used to a large extent for block pavements.

Cement and mastic fillers are discussed further in paragraphs following the accompanying specifications, Tables XL, A and B. (Methods of tests are given in Chap. XIV.)

TABLE XLA.—ASPHALT FOR BITUMINOUS CEMENT AND MASTIC FILLERS

The asphalt shall be homogeneous and free from water. It shall meet the following requirements:

Penetration at 25°C. (77°F.) 100 g.,	{ 30 to 50 for cement filler.
5 sec.	{ 60 to 90 for mastic filler.
Specific gravity at 25°/25°C.	
(77°/77°F.).....	Not less than 1.000
Melting point (ring-and-ball method)	{ 150 to 212°F. for cement filler.
	{ Not over 145°F. for mastic filler.
Flash point.....	Not less than 200°C. (392°F.)
Loss on heating at 163°C. (325°F.)	
50 g., 5 hr.....	Not more than 2 per cent.
Penetration at 25°C. (77°F.) 100 g.	{ Not less than 60 per cent of the
5 sec., of residue.....	{ 25°C. (77°F.) penetration.
Bitumen soluble in carbon disulfide..	Not less than 99.5 per cent.

Note.—See “Native Asphalt and other Products” Chap. XV. For example: Writing the flash point, not less than 190°C. (374°F.); and bitumen soluble in carbon disulfide, not less than 95.0 per cent, would include Bermudez asphalt.

TABLE XLB.—AMERICAN SOCIETY FOR TESTING MATERIALS TENTATIVE SPECIFICATIONS FOR COAL-TAR PITCH FOR STONE BLOCK FILLER

Serial Designation: D112-22T

The coal-tar pitch shall conform to the following requirements:

- (a) Water..... 0.00 per cent.
- (b) Specific gravity at 25°/25°C. (77°/77°F.)..... 1.23 to 1.33.
- (c) Softening point¹ (cube-in-water method)..... 46 to 57°C. (115 to 135°F.)

Note 1.—The Softening point (cube-in-water method) specified should have a range of not over 10°F. within the above limits. The range, within the limits of 115 to 135°F. should vary with the use of the material, for example, if used in admixture with sand, in a northern locality or a southern locality. The softening point range, within the above limits, should also vary according to the character of the paving.

- (d) Distillation test:
 - Total distillate, by weight..... 0 to 300°C. (32 to 572°F.)..... not more than 10.00 per cent.
 - Residue, by weight..... not less than 90.00 per cent.
- (e) Specific gravity at 25°/25°C. (77°/77°F.) of total distillate to 300°C. (572°F.)..... not less than 1.03.
- (f) Softening point (cube-in-water method) of residue from distillation test..... not more than 75°C. (167°F.)
- (g) Ductility at 50 to 100 penetration,² at 25°C. (77°F.)..... not less than 50 cm.

Note 2.—The penetration of the pitch shall be brought within the range of 50 to 100 penetration by heating in an open vessel with frequent stirrings at a temperature of not over 350°F.

- (h) Free carbon..... 20.00 to 35.00 per cent.

325. Bituminous Cement Filler.—In using a bituminous cement alone as a filler it should be applied very hot, especially when the joints are tight, in order that every possible crevice may be filled. Most asphalts suitable for use as fillers may safely be heated to 400°F. and at this temperature good penetration may be obtained. Tar products must not be heated higher than 300°F. and do not require more heat. The paving blocks must be clean and dry when the filler is applied and the weather must not be so cold as to congeal the cement before it fills the crevices. The filler may be poured into the joints from spouted cans as shown in Fig. 180 or, after being emptied on the surface, it may be squeezed into the joints as illustrated in Fig. 181. The former is the better method for wide joints, the latter for tight ones. Whenever prac-

ticable, it is a good plan to have squeegees made of iron and then they may be kept hot. If an excess of filler remains on the sur-



FIG. 180.—Joints between durax blocks half filled with stone grits, then poured with bituminous cement.



FIG. 181.—Applying bituminous cement filler by the squeegee method. Paving brick without lugs, laid with tight joints. (Courtesy of the Paving Brick Assn.)

face a thin coating of coarse sand or stone grits may be spread and then rolled, in order to bed the dressing into the pitch or asphalt coating. The squeegee method is economical from the labor

standpoint, but if carelessly done uses much more bituminous material on the roadway surface. The blocks themselves are the wearing surface of the roadway, and it is unnecessary to cover good block with foreign material. If a bituminous surface is desired it should be constructed of satisfactory thickness and directly on the concrete base.

326. Bituminous Mastic Filler.—The use of mastic filler is practically confined to stone block which have relatively wide and deep joints. Occasionally mastic filler has been used with vitrified lug brick. The sand and the asphalt cement are heated separately to about 400°F. (300°F. in the case of tar cement) and then mixed in about equal proportions. As much sand should be used as possible and still permit the mixture to flow into the joints. Fine sand hangs in suspension in the filler better and does not clog up close joints so easily as coarse sand. Generally a sand all passing the No. 10 sieve and corresponding to that described in Chap. XVI as common to sheet asphalt mixtures is used, the proportions, by volume, being 40 to 50 per cent sand to 60 to 50 per cent asphalt cement. The engineer should determine before hand the correct mixture and his directions should then be accurately carried out. Dependence should not be placed upon the rough guess work of the laborer on the job. After mixing, the usual practice is to transport the hot mixture in barrows, dump it upon the surface of the block and push it into the joints with squeegees.

327. Portland Cement Grout Filler.—In order to obtain a rigid monolithic pavement a grout of equal parts cement and sand has often been poured into the joints of a block surface. With grouted joints there is the objection that traffic must be kept off the street for 10 days or more until the grout sets, and this is necessary not only when the surface is first laid, but whenever a plumber's cut or worn spot is repaired. If the grout does not penetrate to the bottom of the joints, and this often happens, bad defects result as the thrust from expansion then has to be carried by the upper part of the joint only, and this crushes the heads of the blocks. Partial filling of joints when bituminous filler is used does not result in this crushing. Whenever the grout filler wears down or breaks out from between the blocks it cannot be renewed or added to with ease and success as in the case of bituminous filler. Thus there are a good many objectionable features connected with grout filler and its use is not recommended.

328. Sanded Joints.—While sand was at one time the universal filler for joints it is today so used only to a limited extent. For wide joints, instead of using a bituminous mastic, the joints are sometimes partially filled with coarse sand or stone grits and then completely filled with hot bituminous cement. This type of work, however, should not strictly come under the present heading and there, in fact, remains but one type of pavement on which sanded joints are used today; that is, asphalt block. Asphalt blocks are laid with tight joints, then a No. 10 sand is swept into the joints and a thin layer of sand left on the surface for a week or so in order that traffic may iron it into the joints.

329. Parging along Rails.—While sometimes specially shaped blocks are used for paving against railway tracks, the common method is to parge or plaster against the web of the rail and beneath the head and groove, with a 1:2 or 1:3 mortar. The mortar should be struck so as to be even with the vertical planes of the edges of the rail head and groove, and must be kept in position until the paving is laid. The regular run of blocks may then be used and should be bedded with their tops flush with the rail tread surface.

330. Headers.—When a new block pavement adjoins an unimproved roadway, a header is installed for the full width of the new surface in order to hold the last few courses of blocks firmly in place. Headers may be of concrete or other material commonly used for curbing. They are constructed in practically the same manner as curb, except that they are set cross-wise of the roadway and flush with its transverse grade. Old blue stone or other curbing, though no longer suitable for gutter curb is good enough for use as headers.

331. Expansion Joints.—Expansion joints are necessary with grout-filled block pavements, which have a depth of approximately only 4 in., because unlike one course concrete pavements, the slab thickness and strength is not sufficient to take horizontal compression without buckling, which is evidenced by what are usually known as "blow ups." These "blow ups" have been common also with wood block whenever other than bituminous fillers have been used; the expansion in wood block being due to moisture, rather than temperature, as with brick and other types. Usual practice is to use expansion joints parallel with and at each curb $\frac{3}{4}$ in. in width, and next to each side of each railway rail, $\frac{1}{2}$ in. in width. Sometimes other longi-

tudinal and uniformly spaced transverse joints are used, but generally, local movement for a foot or so either side of such joints causes bad spots in the pavement; and such joints are not to be recommended except at abrupt grade changes or crowned roadway intersections.

When bituminous filler is used between the blocks, expansion joints are unnecessary. Some engineers use next to the curbs with hard surface pavements wide joints, $\frac{3}{4}$ to 1 in., filled with bituminous material, not to take care of expansion, but with the hope of isolating the pounding of traffic, thereby eliminating jarring of the sidewalks and buildings. It is doubtful though that this result is achieved.

Expansion joints may be formed, either by inserting, while laying the blocks, prepared bituminous strips, several kinds of which are on the market, or by the pouring method. In pouring expansion joints a cement suitable for bituminous filler is satisfactory. The space for the joint may be formed by placing together on edge two wedge-shaped wood strips which thus give the thickness desired for the joint. These strips are easily withdrawn from the pavement whenever it is desired to pour the joint.

CHAPTER XIX

STONE BLOCK AND CURB

332. New Granite Blocks.—What is known as a 5-in. block illustrated in Fig. 182, has been adopted as a standard for granite

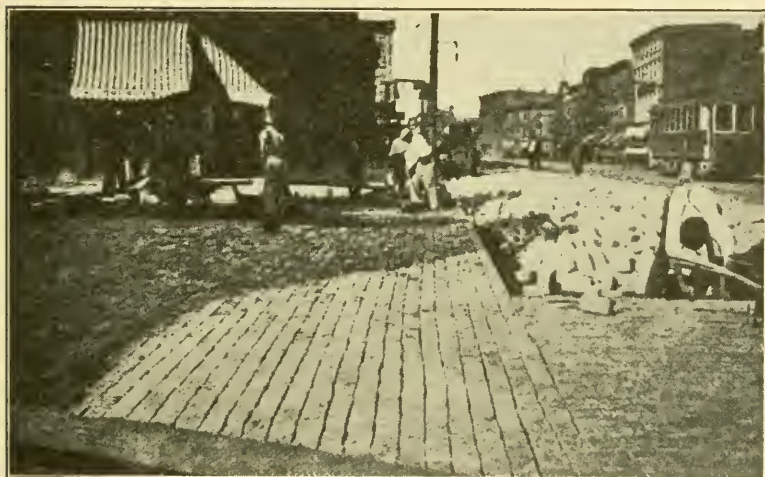


FIG. 182.—Laying 5-in. granite paving blocks. (*Courtesy of the Granite Paving Block Assn.*)

block paving in the United States. Other sizes often used are also shown in the accompanying table:

TABLE XLI.—GRANITE PAVING BLOCKS

Trade name	Dimensions in inches					
	Length		Width		Depth	
	From	To	From	To	From	To
Five-inch.....	8	12	3½	4½	4¾	5¼
Manhattan.....	6	10	3½	4½	4¾	5¼
Four-inch.....	7	11	4	4½	4	4½
Resurfacing.....	7	11	3¾	4¼	3½	4
Hassan.....	6	12	3½	4½	4	4½

Blocks other than the 5-in. Standard are seldom kept in stock by the manufacturers and usually cost more than the Standard. Shallow blocks, less than 5 in. in depth, are sometimes required to meet a demand for granite paving to replace other types of surfaces on existing concrete bases.

Granite Block Specifications.—The City of New York has obtained very good results with its "Manhattan Blocks," specifications for which are as follows:

1. **GRANITE QUALITY.**—The granite from which the blocks are cut shall be medium grained, showing uniformity in quality and texture, without seams, scales or discolorations indicating disintegration, an even distribution of constituent minerals, and free from an excess of mica and feldspar. No outcrop, soft, brittle or seamy stones will be acceptable.

2. **DIMENSIONS.**—The size of the blocks shall be as follows: Not less than 6 in. nor more than 10 in. long; not less than $3\frac{1}{2}$ in. nor more than $4\frac{1}{2}$ in. wide; and not less than $4\frac{3}{4}$ in. nor more than $5\frac{1}{4}$ in. deep.

3. **SELECTION OF WIDTH.**—The contractor shall select a definite width for the blocks to be used on each city block within the limits of this contract and notify the engineer of such selection. All blocks shall be of the selected width with an allowable variation of $\frac{1}{4}$ in. either way from this width, but within the limits for width of blocks specified above.

4. **SPECIAL DIMENSIONS.**—When approved by the engineer, the blocks may be of such other dimensions as special construction may make necessary.

5. **DRESSING.**—The blocks shall be approximately rectangular on top and sides and uniform in width. They shall be so cut that the joints between individual blocks when laid shall average not more than $\frac{3}{8}$ in. The head of the block shall have no depression greater than $\frac{1}{4}$ in. from a straight edge laid in any direction and parallel to the general surface of the block.

6. **DIFFERENT QUARRIES SEPARATED.**—The stones from each quarry shall be piled and laid separately in different sections of the work, and in no case shall the product of different quarries be mixed.

7. **INSPECTION BEFORE DELIVERY.**—The paving blocks will be inspected at the quarry or at the dock as unloaded, and if the percentage of blocks failing to conform to these specifications found in 1,000 blocks, as unloaded, shall exceed 15 per cent, the whole cargo will be condemned and shall not be used on the work.

8. **RE-INSPECTION.**—If permitted by the engineer, the percentage of unsatisfactory blocks may be determined from the examination of another 1,000 blocks, but if this is permitted, before delivery on the street, the unsatisfactory portion of the cargo shall be removed and not delivered on the work.

9. **INSPECTION OF INDIVIDUAL BLOCKS.**—Acceptance of a cargo as described will not be considered as acceptance of all individual blocks, and the engineer will have the right to reject any block on or in the work not conforming to the requirements of the specification.

The Manhattan specifications are very rigid in two particulars which, while turning out a smooth and excellent riding surface, give a block costing much more than most municipalities are willing to pay. These two particulars are: (1) The requirement that joints between individual blocks when laid shall average not more than $\frac{3}{8}$ in. (The American Society for Testing Materials Tentative Specifications D59-19T require: Joints not exceeding $\frac{1}{2}$ in. in width at the top, and for 1 in. down therefrom; and not exceeding 1 in. in width at any other part of the joint.) (2) The requirement that the head of the block shall have no depression greater than $\frac{1}{4}$ in. from a straight edge laid in any direction and parallel to the general surface of the block. (The American Society for Testing Materials Tentative Specifications D59-19T allow $\frac{3}{8}$ in. for such depressions.)

333. Toughness and Abrasion Tests.—It is important to note that the 1922 New York specifications require no laboratory tests, though the American Society for Testing Materials Tentative Specifications D59-19T require:

PHYSICAL PROPERTIES AND TESTS

The average of three tests on sample blocks shall conform to the following requirements as to physical properties:

For Heavy Traffic

French coefficient of wear.....	not less than 11
Toughness.....	not less than 9

For Moderately Heavy Traffic

French coefficient of wear.....	not less than 8
Toughness.....	not less than 7

The American Society for Testing Materials Standard Tests D2-08 for Abrasion of Road Material, and D3-18 for Toughness of Rock are as follows:

TEST FOR ABRASION OF ROAD MATERIAL

1. **SCOPE.**—This well-known method of test is similar in almost all respects to the Deval abrasion test of the French School of Roads and Bridges. It has been used since 1878, and is entirely satisfactory for the purpose for which it was designed.

2. APPARATUS.—The machine (see Fig. 183) shall consist of one or more hollow iron cylinders; closed at one end and furnished with a tightly fitting iron cover at the other; the cylinders to be 20 cm. in diameter and 34 cm. in depth, inside. These cylinders are to be mounted on a shaft at an angle of 30 deg. with the axis of rotation of the shaft.

3. PREPARATION OF SAMPLE.—At least 30 lb. of coarsely broken stone shall be available for a test. The rock to be tested shall be broken in pieces as nearly uniform in size as possible, and as nearly 50 pieces as possible shall constitute a test sample.

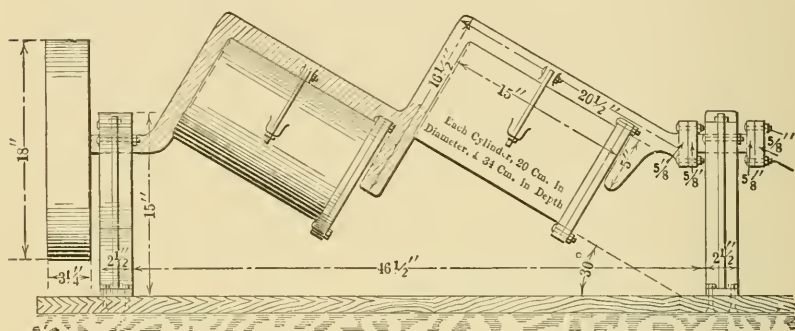


FIG. 183.—Abrasion machine—Deual type.

4. PROCEDURE.—The total weight of rock in a test shall be within 10 g. of 5 kg. All test pieces shall be washed and thoroughly dried before weighing. Ten thousand revolutions, at a rate of between 30 and 33 per minute, shall constitute a test. Only the percentage of material worn off which will pass through a 0.16-cm. ($\frac{1}{16}$ in.) mesh sieve shall be considered in determining the amount of wear. This may be expressed either as the percentage of the 5 kg. used in the test, or the French coefficient, which is in more general use, may be given; that is, coefficient of wear = $20 \times \frac{20}{w} = \frac{400}{w}$, where w is the weight in grams of the detritus under 0.16 cm. ($\frac{1}{16}$ in.) in size per kilogram of rock used.

TEST FOR TOUGHNESS OF ROCK

1. DEFINITION.—Toughness, as applied to rock, is the resistance offered to fracture under impact, expressed as the height of the final blow of a standard hammer required to cause fracture of a cylindrical test specimen of given dimensions.

2. IMPACT MACHINE.—Any form of impact machine which will comply with the following essentials may be used in making the test:

(a) A cast-iron anvil weighing not less than 50 kg., firmly fixed upon a solid foundation.

(b) A hammer weighing 2 kg., arranged so as to fall freely between suitable guides.

(c) A plunger made of hardened steel and weighing 1 kg., arranged to slide freely in a vertical direction in a sleeve, the lower end of the plunger being spherical in shape with a radius of 1 cm.

(d) Means for raising the hammer and for dropping it upon the plunger from any specified height from 1 to not less than 75 cm., and means for determining the height of fall to approximately 1 mm.

(e) Means for holding the cylindrical test specimen securely on the anvil without rigid lateral support and under the plunger in such a way that the center of its upper surface shall throughout the test be tangent to the spherical end of the plunger at its lowest point.

3. **SAMPLES.**—Quarry samples of rock from which test specimens are to be prepared shall measure at least 6 in. on a side and at least 4 in. in thickness, and when possible shall have the plane of structural weakness of the rock plainly marked thereon. Samples shall be taken from freshly quarried material, and only from pieces which show no evidences of incipient fracture due to blasting or other causes. The samples should preferably be split from large pieces by the use of plugs and feathers and not by sledging. Commercial stone-block samples from which test specimens are to be prepared, shall measure at least 3 in. on each edge.

4. **SPECIMENS.**—Specimens for test shall be cylinders prepared as described in Paragraph 5, 25 mm. in height and from 24 to 25 mm. in diameter. Three test specimens shall constitute a test set. The ends of the specimen shall be plane surfaces at right angles to the axis of the cylinder.

5. **PREPARATION OF SPECIMENS.**—One set of specimens shall be drilled perpendicular and another parallel to the plane of structural weakness of the rock, if such plane is apparent. If a plane of structural weakness is not apparent, one set of specimens shall be drilled at random. Specimens shall be drilled in a manner which will not subject the material to undue stresses and which will insure the specified dimensions. The ends of the cylinders may be sawed by means of a band or diamond saw, or in any other way which will not induce incipient fracture, but shall not be chipped or broken off with a hammer. After sawing, the ends of the specimens shall be ground plane with water and carborundum or emery on a cast-iron lap until the cylinders are 25 mm. in length.

6. **THE TEST.**—The test shall consist of a 1-cm. fall of the hammer for the first blow, a 2-cm. fall for the second blow, and an increase of 1-cm. fall for each succeeding blow until failure of the test specimen occurs.

The height of the blow in centimeters at failure shall be the toughness of the test specimen. The individual and the average toughness of three test specimens shall be reported when no plane of structural weakness is apparent. In cases where a plane of structural weakness is apparent, the individual and average toughness of the three specimens

in each set shall be reported and identified. Any peculiar condition of a test specimen which might affect the result, such as the presence of seams, fissures, etc., shall be noted and recorded with the test result.

Note.—An impact testing machine, diamond core drill, diamond saw, and grinding lap are illustrated in *Bulletin 949*, Oct. 10, 1921. U. S. Department of Agriculture.

334. Value of Tests.—The Abrasion and Toughness Tests were originally designed to measure the relative resistance to impact and wear of broken stone for use in macadam roads. To date there are no data showing significant relation between these tests and the actual service of stone blocks in the street. For both tests great care is necessary in making specimens, and there are chances for large errors. The toughness test does not approximate service conditions on the street, and it is doubtful that this impact test on a very small cylinder of stone, 1 in. in diameter and 1 in. high is worth while. Results obtained with the abrasion test have not been uniform enough to warrant basing upon it the choice of any one stone rather than another for paving block. The Bureau of Roads has been developing improvements in the manner of making the test, and it may be possible in the near future to set definite minimum requirements for blocks. For the present the test is useful mainly as a means of showing whether or not any portion of a given shipment of stone from one quarry is disintegrated to any extent.

335. Cost Data.—Typical data (1922) for the cost of a granite block surface are:

	PER SQUARE YARD
30 blocks @ \$120 per thousand.....	\$3.60
Handling to trucks.....	0.03
Hauling.....	0.32
Piling on street.....	0.02
Laying and ramming.....	0.30
Mastic filler.....	0.30
Sand cushion (plus 25 cts. if cement is added).....	0.13
	\$4.60
Contingencies and over-head.....	0.50
Profit.....	0.70
Total estimate.....	\$5.80

336. Recut Paving Blocks.—Many old streets in the United States requiring reconstruction are paved with blocks 10 to 14 in. long, 4 to 5 in. wide, and 7 to 8 in. deep. By splitting these old blocks and redressing them so that the heart is made the new

wearing surface, blocks can be turned out giving a 5-in. depth and running about 40 to the square yard. They should comply with standard specifications as to quality of stone and dressing, also as to permissible variance in width and depth, and surface depressions. The percentage of blocks suitable to produce two recut ones is generally sufficient to overcome the loss in recutting and rejects, so that usually there is a small surplus of blocks. The work of recutting is ordinarily done on the street as illustrated in Fig. 184. This closes the roadway for a long



FIG. 184.—Recutting granite paving blocks. (*Courtesy of the Granite Paving Block Assn.*)

period which is often very objectionable from the traffic standpoint. Recut blocks can be manufactured on the job and piled for about \$30 per thousand, compared to probably more than \$130 per thousand for new blocks delivered on the work. About 40 recut ones are required per yard and from 28 to 30 new blocks. From these data the economy as to cost of construction is apparent. The worth of the recut block pavement compared with one constructed with new blocks depends; first, upon the condition of the old blocks from which the recut ones are made, and then upon the care with which recutting and dressing are carried out.

337. Other Stone Blocks.—In addition to granite, sandstone and basalt blocks have been used, also to a slight extent, limestone. A great deal of Medina sandstone has been used in northern and western New York cities, and with considerable

satisfaction. Sandstones are also used extensively in Minnesota and Colorado. The variety of stone now rendering good service as paving blocks, though giving widely different results in the Toughness and Abrasion Tests, makes apparent that there is some justification for doubt as to the fitness of these tests.

338. Durax Pavement.—Specifications approved by the American Society for Municipal Improvements in 1921, for Durax paving blocks require:

Durax paving blocks shall be cut from granite complying with the requirements specified for new granite paving blocks.

The blocks shall be cubes of granite with six approximately square surfaces, the edges of which measure not more than four (4) nor less than three (3) inches in length. They shall be dressed so as to conform with the requirements specified for new granite blocks except as to form and dimensions.

Durax blocks give a cheaper pavement than do standard granite blocks, one reason being their less depth. This less depth is taken advantage of for resurfacing over existing concrete bases where depth is necessarily restricted. Durax blocks run from 75 to 100 per square yard, and cost from \$20 to \$30 per thousand. About the same amount of filler per square yard of pavement is required as for standard blocks.

339. Stone Curb.—A great variety of stone is used for curbing along city roadways, the most common being probably blue stone. Granite is undoubtedly the best material, though costly especially if it has to be shipped a long distance. Local sandstones and limestones, from soft to hard, varying with their source, are used extensively. Any material used should be of uniform texture and color, free from seams, laminations and disintegration. Usually curb is purchased upon visual inspection from known sources, but in addition some engineers include a "Rattler Test" (see Chap. XX) or the "Deval Abrasion Test" (described in the present chapter). For the former with four blocks, about 5 by 6 by 10 in. each, the loss by abrasion is specified at not more than 12 per cent. For the Deval test a coefficient of wear of seven is permissible. An absorption test is sometimes specified, restricting absorption to not exceeding $2\frac{1}{2}$ per cent after an immersion of 48 hr.

The general question of the choice of materials for curb was discussed in Chap. V wherein was pointed out also, the advantage of using an 8 by 8-in. curb instead of a narrower top

width and greater depth. In Fig. 185 is illustrated an 8 by 8-in. granite curb properly bedded on a concrete foundation. Pieces of curb should be purchased in such lengths as not to be too heavy for handling. While stone from some quarries has to be accepted in short lengths, 3 ft. or better still, 40 in. should be set as a minimum for curb for general use. Eight by eight granite curb is usually used in lengths from 6 to 12 ft. Circular curb should be ordered cut to given lengths and radii, with the ends dressed on radial lines.



FIG. 185.—Granite curb, 8 by 8 in., bedded on a concrete foundation.

Although much roughly dressed stone curb is in existence on city streets it is generally conceded that if the purchase of granite is justified, then also is the expense necessary for having it fine peen hammer dressed. A specification calling for a variance of not more than $\frac{1}{4}$ in. from a plane surface for the face, top, and for the back to a depth of 1 in. from the top, is believed to be not too rigid. The top should be cut on a bevel as stated under "Curb Height and Slope," Chap. VI. The ends should be dressed so as to give neat close joints not greater than $\frac{1}{4}$ in. in width. These joints need no mortar. The back and bottom should be free from excessive protuberances. The depth may be an inch or two greater but not less than the minimum specified.

CHAPTER XX

PAVING BRICK

340. Character of Brick.—Bricks commonly used for roadways are vitrified and should be thoroughly annealed, tough and durable, regular in size and shape, and evenly burned. When broken they should show a dense, stone-like body, free from lime, air pockets, cracks, or marked laminations. Kiln marks should not exceed $\frac{3}{16}$ in., and the wearing surface should show but slight kiln marks.

341. Varieties of Brick.—Through the efforts of the U. S. Department of Commerce the varieties of paving brick have been reduced from 66, until finally on Mar. 27, 1922, but seven types remained as "recognized types and sizes," as shown in Table XLII.

TABLE XLII.—RECOGNIZED TYPES AND SIZES OF BRICK

Type	Dimensions	Depth as laid
Plain wire cut.....	3 by 4 by $8\frac{1}{2}$ in.	3 or 4 in.
Plain wire cut.....	$3\frac{1}{2}$ by 4 by $8\frac{1}{2}$ in.	$3\frac{1}{2}$ or 4 in.
Repressed lug.....	$3\frac{1}{2}$ by 4 by $8\frac{1}{2}$ in.	4 in.
Wire cut lug.....	$3\frac{1}{2}$ by 4 by $8\frac{1}{2}$ in.	4 in.
Wire cut lug.....	$3\frac{1}{2}$ by $3\frac{1}{2}$ by $8\frac{1}{2}$ in.	$3\frac{1}{2}$ in.
Wire cut lug.....	$3\frac{1}{2}$ by 3 by $8\frac{1}{2}$ in.	3 in.
Repressed hillside.....	$3\frac{1}{2}$ by 4 by $8\frac{1}{2}$ in.	4 in.

Plain wire-cut brick should have square edges. Lug brick may have rounded edges, the radius not exceeding $\frac{1}{4}$ in. With all wire-cut brick the ends may be double-beveled not to exceed $\frac{3}{32}$ in. Brick should not vary from the specified dimensions more than $\frac{1}{8}$ in. in width or depth nor more than $\frac{1}{2}$ in. in length. Lugs should extend from the body of the brick not more than $\frac{1}{4}$ nor less than $\frac{1}{8}$ in.

One point stressed by the National Paving Brick Manufacturers Association in favor of the plain wire-cut brick is that, having

no lugs, two requirements as to depth may be satisfied with one brick. For instance the 3 by 4 brick which is known as the Association's "Standard Brick" may be laid with either a depth of 3 in. or 4 in., in the first case requiring approximately 36 brick per square yard of pavement and with the 4-in. depth approximately 48 per square yard. The $3\frac{1}{2}$ by 4 brick are known by the Association as "Block Size."

342. Specifications.—The American Society for Testing Materials Standard Specifications, C7-15 for paving brick are as follows:

SCOPE.—The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure:

I. The rattler test for the purpose of determining whether the material as a whole possesses to a sufficient degree strength, toughness, and hardness.

II. Visual inspection for the purpose of determining whether the physical properties of the material as to dimensions, accuracy, and uniformity of shape and color are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

The acceptance of paving brick as satisfactorily meeting one of these tests shall not be construed as in any way waiving the other.

1. THE RATTLER TESTS

1. PLACE OF SAMPLING.—In general, where a shipment of bricks involving a quantity in excess of 100,000 is under consideration, the sampling shall be done at the factory prior to shipment. Bricks accepted as the result of test prior to shipment shall not be liable to subsequent rejection as a whole, but are subject to such culling as is provided for under Part II, visual inspection.

2. METHOD OF SELECTING SAMPLES.—In general, the buyer shall select his own samples from the material which the seller proposes to furnish. The seller shall have the right to be present during the selection of a sample. The sampler shall endeavor, to the best of his judgment, to select brick representing the average of the lot. No samples shall include bricks which would be rejected by visual inspection, as provided in Part II, except that where controversy arises whole tests may be selected to determine the admissibility of certain types or portions of the lot having a characteristic appearance in common. In cases where prolonged controversy occurs between buyer and seller and samples selected by each party fail to show reasonable concurrence, then

both parties shall unite in the selection of a disinterested person to select the samples, and both parties shall be bound by the results of samples thus selected.

3. NUMBER OF SAMPLES PER LOT.—In general, one sample of 10 bricks shall be tested for every 10,000 bricks contained in the lot under consideration; but where the total quantity exceeds 100,000 the number of samples tested may be fewer than 1 per 10,000 provided that they shall be distributed as uniformly as practicable over the entire lot.

4. SHIPMENT OF SAMPLES.—Samples which must be transported long distances by freight or express shall be carefully put up in packages holding not more than 12 bricks each. When more than six bricks are

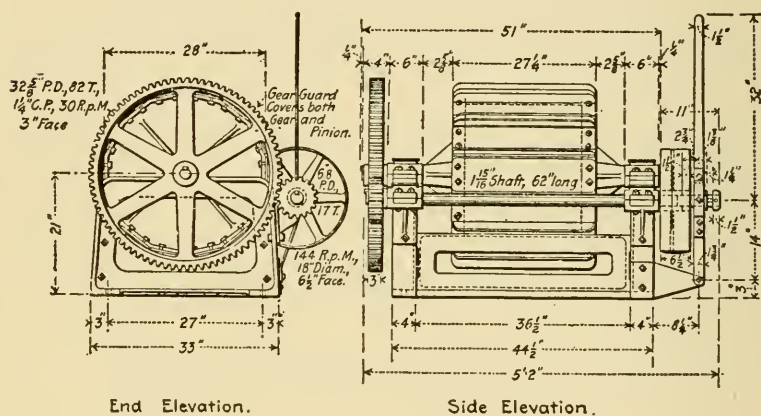


FIG. 186.

shipped in one package, it shall be so arranged as to carry two parallel rows of bricks side by side and these rows shall be separated by a partition. In event of some of the bricks being cracked or broken in transit, the sample shall be disqualified if there are not remaining 10 sound undamaged bricks.

5. STORAGE AND CARE OF SAMPLES.—Samples shall be carefully handled to avoid breakage or injury. They shall be kept in the dry so far as practicable. If wet when received, or known to have been immersed or subjected to recent prolonged wetting, they shall be dried for at least 6 hr. in a temperature of 100°F. before testing.

6. GENERAL DESIGN.—The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described (see Fig. 186).

7. THE BARREL.—The barrel of the machine shall be made up of the heads, head liners, staves, and stave liners.

The heads may be cast in one piece with the trunnions, which shall be $2\frac{1}{2}$ in. in diameter, and shall have a bearing 6 in. in length, or they may be cast with heavy hubs, which shall be bored out for $27\frac{1}{16}$ in. shafts, and shall be key-seated for two keys, each $\frac{1}{2}$ by $\frac{3}{8}$ in. and spaced 90 deg. apart. The shaft shall be a snug fit, and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside face of the head shall be $15\frac{3}{8}$ in. in the head for the driving end of the rattler, and $11\frac{3}{8}$ in. for the other head, and the distance from the face of the hubs to the inside face of the heads shall be $5\frac{1}{8}$ in.

The heads shall be not less than $\frac{3}{4}$ in. thick, nor more than $\frac{7}{8}$ in. thick. In outline, each head shall be a regular 14-sided polygon inscribed in a circle $28\frac{3}{4}$ in. in diameter. Each head shall be provided with flanges not less than $\frac{3}{4}$ in. thick and extending outward $2\frac{1}{2}$ in. from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head shall be smooth and give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head shall be either ground or machined. The flanges shall be slotted on the outer edge so as to provide for two $\frac{3}{4}$ -in. bolts at each end of each stave, said slots to be $1\frac{3}{16}$ in. wide and $2\frac{3}{4}$ in. center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace $\frac{3}{8}$ in. thick, extending down the outward side of the head not less than 2 in.

There shall be for each head a cast-iron head liner 1 in. in thickness and conforming to the outline of the head, but inscribed in a circle $28\frac{1}{8}$ in. in diameter. This head liner shall be fastened to the head by seven $\frac{5}{8}$ -in. cap screws, through the head from the outside. Whenever these head liners become worn down $\frac{1}{2}$ in. below their initial surface level at any point of their surface, they shall be replaced with new ones. The metal of these head liners shall be hard machinery iron and should contain not less than 1 per cent of combined carbon.

The staves shall be made of 6-in. medium-steel structural channels $27\frac{1}{4}$ in. long and weighing 15.5 lb. per linear foot. The staves shall have two holes $1\frac{3}{16}$ in. in diameter, drilled in each end, the center line of the holes being 1 in. from the end and $1\frac{3}{8}$ in. either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but shall not exceed $\frac{5}{16}$ in.

The interior or flat side of each stave shall be protected by a liner $\frac{3}{8}$ in. thick by $5\frac{1}{2}$ in. wide by $19\frac{3}{4}$ in. long. The liner shall consist of medium-steel plate, and shall be riveted to the channel by three $\frac{1}{2}$ -in. rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7 in. from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of

the liners. These liners shall be inspected from time to time, and if found loose shall be at once riveted.

Any test at the expiration of which a stave liner is found detached from the stave or seriously out of position shall be rejected. When a new rattler, in which a complete set of new staves is furnished, is first put into operation, it shall be charged with 400 lb. of shot of the same sizes and in the same proportions as provided in Sec. 9, and shall then be run for 18,000 revolutions at the usual prescribed rate of speed. The shot shall then be removed and a standard shot charge inserted, after which the rattler may be charged with brick for a test.

No stave shall be used for more than 70 consecutive tests without renewing its lining. Two of the 14 staves shall be removed and relined at a time in such a way that of each pair, one falls upon one side of the barrel and the other upon the opposite side, and also so that the staves changed shall be consecutive but not contiguous, for example, 1 and 8, 3 and 10, 5 and 12, 7 and 14, 2 and 9, 4 and 11, 6 and 13, etc., to the end that the interior of the barrel at all times shall present the same relative condition of repair. The changes in the staves should be made at the time when the shot charges are being corrected, and the record must show the number of charges run since the last pair of new lined staves was placed in position.

The staves when bolted to the heads shall form a barrel 20 in. long, inside measurement, between headliners. The liners of the staves shall be so placed as to drop between the headliners. The staves shall be bolted tightly to the heads by four $\frac{3}{4}$ -in. bolts, and each bolt shall be provided with a lock nut, and shall be inspected at not less frequent intervals than every fifth test and all nuts kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

8. THE FRAME AND DRIVING MECHANISM.—The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support it without undue vibration. It shall rest on a rigid foundation with or without the interposition of wooden plates, and shall be fastened thereto by bolts at not less than four points.

It shall be driven by gearing whose ratio of driver to driven is not less than 1:4. The countershaft upon which the driving pinion is mounted shall not be less than $1\frac{5}{16}$ in. in diameter, with bearing not less than 6 in. in length. If a belt drive is used the pulley shall not be less than 18 in. in diameter and $6\frac{1}{2}$ in. in face. A belt at least 6 in. in width properly adjusted, to avoid unnecessary slipping, should be used.

9. THE ABRASIVE CHARGE.—The abrasive charge shall consist of cast-iron spheres of two sizes. When new, the larger spheres shall be 3.75 in. in diameter and shall weigh approximately 7.5 lb. (3.40 kg.) each. Ten spheres of this size shall be used.

These shall be weighed separately after each 10 tests, and if the weight of any large sphere falls to 7 lb. (3.175 kg.) it shall be discarded and a new

one substituted; provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear.

When new, the smaller spheres shall be 1.875 in. in diameter and shall weigh approximately 0.95 lb. (0.43 kg.) each. In general, the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly 300 lb. as possible. No small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1.75 in. in diameter, drilled in an iron plate $\frac{1}{4}$ in. in thickness, or weigh less than 0.75 lb. (0.34 kg.). Further, the small spheres shall be tested, by passing them over the above plate or by weighing, after every 10 tests, and any which pass through or fall below the specified weight, shall be replaced by new spheres; provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective, it shall at once be replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon.....	Not under 2.50 per cent
Graphitic carbon.....	Not over 0.25 per cent
Silicon.....	Not over 1.00 per cent
Manganese.....	Not over 0.50 per cent
Phosphorus.....	Not over 0.25 per cent
Sulphur	Not over 0.08 per cent

For each new batch of spheres used, the chemical analysis shall be furnished by the maker or be obtained by the user, before introducing into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

10. THE BRICK CHARGE.—The number of bricks per test shall be 10 for all bricks of so-called "block-size," whose dimensions fall between 8 and 9 in. in length, 3 and $3\frac{3}{4}$ in. in breadth, and $3\frac{3}{4}$ and $4\frac{1}{4}$ in. in thickness.¹

No brick should be tested as a part of a regular test that would be rejected by any other requirements of the specifications under which the purchase is made.

11. SPEED AND DURATION OF REVOLUTION.—The rattler shall be rotated at a uniform rate of not less than 29.5 nor more than 30.5 r.p.m.,

¹ Where brick of larger or smaller sizes than the dimensions given above for blocks are to be tested, the same number of bricks per charge should be used, but allowance for the difference in size should be made for setting the limits for average and maximum rattler loss.

and 1,800 revolutions shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin not to exceed 10 revolutions will be allowed for stopping. Only one start and stop per test is generally acceptable. If, from accidental causes, the rattler is stopped and started more than once during a test, and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

12. **THE SCALES.**—The scales must have a capacity of not less than 300 lb., and must be sensitive to 0.5 oz., and must be tested by a standard test weight at intervals of not less than every 10 tests.

13. **THE RESULTS.**—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb. shall be rejected.

14. **THE RECORDS.**—A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made:

1. The name of the person, firm, or corporation furnishing each sample tested.

2. The name of the maker of the brick represented in each sample tested.

3. The name of the street, or contract, which the sample represented.

4. The brands or marks upon the bricks by which they were identified.

5. The number of bricks furnished.

6. The dates on which they were received for test and tested.

7. The drying treatment given before testing, if any.

8. The length, breadth, and thickness of the bricks.

9. The collective weight of the 10 large spherical shot used in making the test at the time of their last standardization.

10. The number and collective weight of the small spherical shot used in making the test at the time of their last standardization.

11. The total weight of the shot charge after its last standardization.

12. Certificate of the operator that he examined the condition of the machine as to staves, liners, and any other parts affecting the barrel, and found them right at the beginning of the test.

13. Certificate of the operator of the number of charges tested since the last standardization of shot charge and last renewals of stave liners.

14. The time of the beginning and ending of each test, and the number of revolutions made by the barrel during the test, as shown by the indicator.

15. Certificate of the operator as to number of stops and starts made in each test.

16. The initial collective weight of the 10 bricks composing the charge and their collective weight after rattling.

17. The loss calculated in percentage of the initial weight; and the calculation itself.

18. The number of broken bricks and remarks upon the portions which were included in the final weighing.

19. General remarks upon the test and any irregularities occurring in its execution.

20. The date upon which the test was made.

21. The location of the rattler, upon which the test was made, and name of the owner.

22. The certificate of the operator that the test was made under the specifications of the American Society for Testing Materials and that the record is a true record.

23. The signature of the operator or person responsible for the test.

24. The serial number of the test.

In the event of more than one copy of the record of any test being required, they may be furnished on separate sheets and marked duplicates, but the original record shall always be preserved intact and complete.

For the convenience of the public, the accompanying blank form, Table XLIII, which provides space for the necessary data, is furnished and its use recommended.

TABLE XLIII.—REPORT OF STANDARD RATTLER TEST OF PAVING BRICK

Identification data

Name of the firm furnishing sample.....
 Name of the firm manufacturing sample.....
 Street or job which sample represents.....
 Brands or marks on the brick.....
 Quantity furnished..... Drying treatment.....
 Date received..... Date tested.....
 Length..... Breadth..... Thickness.....

Standardization data

Weight of charge (after standardization)	Condition of lock nuts on staves	Condition of staves	Number and position of fresh stave liners	Repairs (note any repairs affecting the condition of the barrel)
10 large spheres.....				
Small spheres.....				
Total.....				

Number of charges tested since last inspection.....

Running data

	Time readings			Revolution counter readings	Running notes, stops, etc.
	Hours	Minutes	Seconds		
Beginning of test.....					
Final reading.....					

Weights and calculations

		Percentage loss (the calculation must appear)
Initial weight of 10 bricks.....		
Final weight of same.....		
Loss of weight.....		

Number of broken bricks and remarks on same.....

I certify that the foregoing test was made under the specifications of the American Society for Testing Materials, and is a true record.

(Signature of tester).....

Date.....

Location of laboratory.....

15. BASIS OF ACCEPTANCE OR REJECTION.—Paving bricks shall not be judged for acceptance or rejection by the results of individual tests, but by the average of no less than five tests. Where a lot of bricks fail to meet the required average, it shall be optional with the buyer whether the bricks shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Sec. 16.

16. RANGE OF FLUCTUATION.—Some fluctuation in the results of the rattler test, both on account of variations in the bricks and in the machine used in testing, are unavoidable, and a reasonable allowance for such fluctuations should be made wherever the standard may be fixed.

In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than 2 per cent, then the portion of the lot represented by that test shall be at once resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than 2 per cent the required standard, then that portion of the lot shall be rejected.

If in any lot of brick two or more tests exceed the permissible maximum, then the buyer may at his option reject the entire lot, even though the average of all the tests executed may be within the required limits.

17. **FIXING OF STANDARDS.**—The percentage of loss which may be taken as the standard will not be fixed in these specifications, and shall remain within the province of the contracting parties. For the information of the public, the following scale of average losses, Table XLIV is given, representing what may be expected of tests executed under the foregoing specifications:

TABLE XLIV.—RATTLER TEST LOSSES

	General average loss, per cent	Maxi- mum per- missible loss, per cent
For bricks suitable for heavy traffic.	22	24
For bricks suitable for medium traffic.	24	26
For bricks suitable for light traffic.	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer and should be governed by the kind and amount of traffic to be carried and the quality of paving bricks available.

18. **CULLING AND RETESTING.**—Where, under Sec. 15 and 16, a lot or portion of a lot of bricks is rejected, either by reason of failure to show a low enough average test or because of tests above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion which he considers at fault and retaining that which he considers good. When the regrading is complete, the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot or portion under test.

19. **PAYMENT OF COST OF TESTING.**—Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer (see also Sec. 23). The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it shall be paid by the seller, whether the material is finally accepted or rejected.

II. VISUAL INSPECTION

SCOPE.—It shall be the right of the buyer to inspect the bricks, subsequent to their delivery at the place of use and prior to or during laying, to cull out and reject upon the following grounds.

20. **BROKEN BRICKS.**—All bricks which are broken in two or chipped in such a manner that neither wearing surface remains substantially intact, or that the lower or bearing surface is reduced in area by more than one-fifth. Where bricks are rejected upon this ground, it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half bricks for breaking courses and making closures, instead of breaking otherwise whole and sound bricks for this purpose.

21. **CRACKED BRICKS.**—All bricks which are cracked in such a degree as to produce defects such as are defined in Sec. 20, either from shocks received in shipment and handling or from defective conditions of manufacture, especially in drying, burning, or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

22. **OFFSIZE.**—All bricks which are so offsize, or so misshapen, bent, twisted, or kiln marked, that they will not form a proper surface as defined by the paving specifications, or align with other bricks without making joints other than those permitted in the paving specifications.

23. **SOFT BRICKS.**—All bricks which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in Part I, and if in either or both tests the bricks fall beyond the maximum rattler losses permitted under the specifications, then all bricks having the same objectionable appearance may be excluded, and the seller shall pay for the cost of the test. But if under such procedure the bricks which have been tested as objectionable shall pass the rattler test, both tests falling within the permitted maximum, then the buyer cannot exclude the class of material represented by this test and he shall pay for the cost of the test.

24. **COLOR OF BRICKS.**—All bricks which differ so markedly in color from the type or average of the shipment as to make the resultant pavement checkered or disagreeably mottled in appearance. This section shall not be held to apply to the normal variations in color which may occur in the product of one plant among bricks, which will meet the rattler test but shall apply only to differences of color which imply differences in the material of which the bricks are made, or extreme differences in manufacture.

In addition to the tests prescribed by the American Society for Testing Materials the Bureau of Public Roads recommends that an absorption test be made on five rattled brick, which should be immersed in water for 48 hr.; the absorption to be expressed in per cent of the weight of the brick before immersion. This test is adopted by many as a measure of density and degree of vitrifi-

cation of the brick, two properties which, however, are generally assumed to be satisfactorily taken care of by the rattler test.

343. Cost Data.—Typical data (1922) for the cost of a brick surface per square yard are as follows:

	PER SQUARE YARD
36 bricks @ \$50 per thousand (3-in. depth).....	\$1.80
Handling to trucks.....	0.02
Hauling.....	0.20
Piling on street.....	0.02
Laying and rolling.....	0.10
Bituminous filler (plus 10 to 15 cts. if poured).....	0.18
Sand cushion (plus 10 cts. if cement is added).....	0.08
	\$2.40
15 per cent contingencies and over-head.....	0.36
15 per cent profit.....	0.36
Estimate.....	\$3.12

CHAPTER XXI

WOOD BLOCK

344. Wood Block Specifications.—Wood blocks are made both plain and with lugs. Joints should be not more than $\frac{1}{8}$ in. in width and yet should have sufficient width to permit penetration of the filler between the blocks. Advocates of lug blocks claim that the lugs permit accurate spacing and provide for bituminous filler entirely around all sides of each block and thus when expansion takes place during wet or humid weather the pressure exerted is adequately taken care of without buckling of the pavement.

Since development of the paint coat bed some manufacturers have favored a $2\frac{1}{2}$ -in. deep block rather than the 3 to 4-in. blocks that have been commonly used in the past. It is claimed that the $2\frac{1}{2}$ -in. block on a paint coat will, at less cost be as durable and serviceable as blocks of greater depth paved on a sand cushion.

American Society for Testing Materials Standard Specifications D52-20 are as follows:

1. **MATERIAL COVERED.**—These specifications cover wooden paving blocks for pavements exposed to alternate wet and dry conditions, as distinguished from pavements which are used under cover and protected from atmospheric influences.

2. **KIND OF TIMBER.**—The wood, which shall be treated, shall be southern yellow pine, Douglas fir, tamarack, Norway pine, hemlock, or black gum. Only one kind of wood shall be used in any one contract. The blocks shall be sound, and shall be well manufactured, square-butted, square-edged, free from unsound, loose or hollow knots, knot holes, worm holes, and other defects such as shakes, checks, etc., that would be detrimental to the blocks.

3. **QUALITY OF TIMBER.**—The number of annual rings in the 1 in. which begins 2 in. from the pith of the block shall not be less than six, measured radially; provided, however, that blocks containing between five and six rings in this inch shall be accepted if they contain $33\frac{1}{3}$ per cent or more summer-wood. In case the block does not contain the pith, the 1 in. to be used shall begin 1 in. away from the ring which is nearest to the heart of the block. The blocks in each charge shall con-

tain an average of at least 70 per cent of heart wood. No one block shall be accepted that contains less than 50 per cent of heart wood.

4. SIZE OF BLOCKS.—The blocks shall be from 5 to 10 in. long, but should preferably average two times the depth; they shall be * in. in depth.¹ They may be from 3 to 4 in. in width, but in any one city block all of them shall be of uniform width. A variation of $\frac{1}{16}$ in. shall be allowed in the depth and $\frac{1}{8}$ in. in the width of the blocks from that specified. In all cases the width shall be greater or less than the depth by at least $\frac{1}{4}$ in.

5. TREATMENT.—The timber may be either air-seasoned or green, but should preferably be treated within 3 months from the time it is sawed. Green timber and seasoned timber shall not, however, be treated together in the same charge. The blocks shall be treated in an air-tight cylinder with the preservative specified by the purchaser. In all cases, whether thoroughly air-seasoned or green, they shall first be subjected to live steam at a temperature between 220 and 240°F.² for not less than 2 hr. nor more than 4 hr., at the discretion of the treating plant operator, after which they shall be subjected to a vacuum of not less than 22 in. held for at least 1 hr. While the vacuum is still on, the preservative oil, heated to a temperature of between 180 and 220°F., shall be run in until the cylinder is completely filled, care being taken that no air is admitted. Pressure shall then be gradually applied not to exceed 50 lb. at the end of the first hour nor 100 lb. at the end of the second hour, and then maintained at not less than 100 lb. nor more than 150 lb. until the wood has absorbed the required amount of oil.³

After this a supplemental vacuum, in which the maximum intensity reached is at least 20 in. and the time the vacuum is applied not less than 30 min., shall be applied. If desired, this vacuum may be followed by a short steaming period.

6. PENETRATION OF PRESERVATIVE.—In any charge blocks shall contain at least 16 lb. of water-free oil per cubic foot of wood at the completion of the treatment. The blocks after treatment shall show satisfactory penetration of the preservative, and in all cases the oil shall be diffused throughout the sap wood. To determine this, at least 25 blocks should be selected from various parts of each charge and sawed in half perpendicular to the fibers through the center, and if more than one of

¹ It is recommended that blocks 4 in. in depth be used for streets with very heavy traffic, and blocks $3\frac{1}{2}$ in. in depth for streets with moderate traffic. For streets with light traffic blocks 3 in. in depth may be used, but where 3-in. blocks are used no block shall be longer than 8 in.

² In no case shall a steam pressure of 20 lb. per square inch be exceeded.

³ This treatment is recommended for yellow pine only. It is probably also suited to Norway pine, hemlock, black gum and tamarack, but not to Douglas fir. Further recommendations on the treatment of these species are reserved for the future.

these blocks show untreated sap wood, the charge shall be re-treated. After re-treating, the charge shall be again subjected to a similar inspection.

7. **HANDLING BLOCKS AFTER TREATMENT.**—Blocks shall preferably be laid in the street as soon as possible after being treated. If they cannot be laid immediately, provision shall be made to prevent them from drying out by stacking in close piles and covering them, and, if possible, by sprinkling them thoroughly at intervals. In any case, where they are not laid as soon as they are received on the street, they shall be well sprinkled about two days before being laid, under the direction of the purchaser. It is important to have the wood sufficiently wet to be swelled to its maximum size before it is laid.

8. **PRESERVATIVE.**—The preservative used shall be coal-tar paving oil or distillate oil, as specified by the purchaser.

9. **INSPECTION AT PLANT.**—All material herein specified and processes used in the manufacture of the blocks there from shall be subject to inspection, acceptance, or rejection at the plant of the manufacture, which shall be equipped with all the necessary gauges, appliances, and facilities to enable the inspector to satisfy himself that the requirements of the specifications are being fulfilled.

10. **INSPECTION AT STREET.**—The purchaser shall have the further right to inspect the blocks after delivery upon the street, for the purpose of rejecting any blocks that do not meet these specifications; except that the plant inspection shall be final with respect to the kind of wood, number of rings per inch, oil, and treatment.

345. Preservative.—While a pure product known as creosote oil, which is distilled from coal-gas tar or coke-oven tar, is most generally adopted for wood preservation, a mixture of creosote and refined tar is often used. Information is meager as to the relative worth of these two preservatives in connection with paving blocks. In the 1915 manual of the American Railway Engineering Association it is stated "This specification (Creosote-Coal-tar Solution) is submitted for the guidance of those desiring to use the coal tar addition to creosote, which practice is firmly established and widely followed. The creosote-coal-tar solution is not recommended as equal to creosote in preservative qualities, and should be used only when the available supply of creosote is inadequate." When refined tar is added to preservative for paving block it is probably with the desire of increasing the waterproofing properties of the oil. Blocks treated with a creosote-tar mixture undoubtedly bleed more than do those treated with pure creosote. There are a few cities which

specify refined water-gas tar instead of coal-tar products. Specifications adopted 1921 by the American Society of Municipal Improvements are as follows:

1. COAL-TAR-DISTILLATE OIL.—The oil shall be a distillate of coal-gas tar or coke-oven tar, and shall comply with the following requirements:

1. It shall not contain more than 3 per cent of water.

2. It shall not contain more than 0.5 per cent of matter insoluble in benzol.

3. The specific gravity of the oil at 38°C., shall be not less than 1.06.

4. The distillates, based on water-free oil, shall be within the following limits:

Up to 210°C. not more than 5 per cent.

Up to 235°C. not more than 15 per cent.

The residue above 355°C., if it exceeds 10 per cent, shall have a float test of not more than 50 sec. at 70°C.

5. The specific gravity of the fraction between 235 and 315°C. shall be not less than 1.03 at 38°/15.5°C.

The specific gravity of the fraction between 315 and 355°C. shall be not less than 1.10 at 38°/15.5°C.

6. The oil shall yield not more than 2 per cent of coke residue.

2. COAL-TAR PAVING OIL.—The oil shall be a coal-tar product of which at least 65 per cent shall be a distillate of coal-gas tar or coke-oven tar, and the remainder shall be refined or filtered coal-gas tar or coke-oven tar. It shall comply with the following requirements:

1. It shall not contain more than 3 per cent of water.

2. It shall not contain more than 3 per cent of matter insoluble in benzol.

3. The specific gravity of the oil at 38°C. shall not be less than 1.07 nor more than 1.12.

4. The distillates, based on water-free oil, shall be within the following limits:

Up to 210°C. not more than 5 per cent.

Up to 235°C. not more than 25 per cent.

The residue above 355°C., if it exceeds 35 per cent, shall have a float test of not more than 80 sec. at 70°C.

5. The specific gravity of the fraction between 235 and 315°C. shall not be less than 1.03 at 38°/15.5°C.

The specific gravity of the fraction between 315 and 355°C. shall not be less than 1.10 at 38°/15.5°C.

6. The oil shall not yield more than 10 per cent coke residue.

3. WATER-GAS TAR.—The preservative shall be refined water-gas tar, and shall comply with the following requirements:

1. The specific gravity shall be not less than 1.12 nor more than 1.14 at 38°C., referred to water at the same temperature.

2. Not more than 2.0 per cent shall be insoluble by hot extraction with benzol and chloroform.

3. On distillation the distillate, based on water-free oil, shall be within the following limits:

Up to 210°C., not more than 5.0 per cent

Up to 235°C., not more than 15.0 per cent

Up to 315°C., not more than 40.0 per cent

Up to 355°C., not less than 25.0 per cent

4. The specific gravity of the total distillate below 355°C., shall not be less than 1.00 at 38°C., referred to water at the same temperature.

5. The oil shall not contain more than 2.0 per cent water and due allowance shall be made for all water and insoluble foreign matter it may contain by injecting a corresponding additional quantity into the blocks.

346. Tests for Preservative.—The Standard Methods of the American Society for Testing Materials for the sampling and analysis of creosote oil, serial designation; D38-18 are as follows:

I. SAMPLING

1. **CONTINUOUS DRIP SAMPLE.**—Wherever the oil is being loaded or discharged by means of a pump the following method shall be used:

A ½-in. sampling pipe shall be inserted in the line through which the oil is being pumped, on the discharge side of the pump, preferably in a rising section of the pipe line. This sampling pipe shall extend one-half way to the center of the main pipe and with the inner open end of the sampling pipe turned at an angle of 90 deg. and facing the flow of the liquid. This pipe shall be provided with a plug cock and shall discharge into a receiver of 50 to 100-gal. capacity. The plug cock shall be so adjusted that, with a steady continuous flow of the oil, the receiver shall be filled in the time required to pump the entire shipment. The receiver shall be provided with a steam coil sufficient to keep the contents at a temperature not exceeding 120°F. Immediately upon completion of the pumping, the contents of the receiver shall be very thoroughly agitated and a duplicate 1-qt. sample taken immediately for the test. The amount of the drip sample collected shall be not less than 1 gal. for each 1,000 gal. of oil handled, except in the case of large boat shipments, where a maximum of 100 gal. is sufficient.

II. WATER

2. **APPARATUS.** (a) *Still.*—A vertical, cylindrical copper still, with removable flanged top and yoke; of the form and approximate dimensions shown in Fig. *,¹ shall be used.

¹See Fig. 139, "Test for Water" Chap. XIV.

(b) *Thermometer*.—The standard distillation thermometer, as specified under "Distillation," Sec. V, shall be used.

(c) *Condenser*.—A copper trough condenser shall be used, with straight-walled glass tube, having approximately the form and dimensions shown in Fig. *.¹

(d) *Separatory Funnel*.—A separatory funnel of the form shown in Fig. *.¹ shall be used, having a total capacity of 120 c.c., and the outlet graduated in fifths of a cubic centimeter.

(e) *Assembled Apparatus*.—The apparatus shall be set up as shown in Fig. *.¹

3. **WATER TEST.**—When any measurable amount of water is present in the distillate below 210°C. on testing in accordance with Sec. V on "Distillation," the oil and water in this fraction shall be separated, if possible, and measured separately. If more than 2 per cent of water is present, or if the water is apparently present to an extent in excess of 2 per cent, but an accurate separation is impossible, the percentage of water present shall be determined by the following method, and the water-free oil so obtained shall be used in the distillation test:

Measure 200 c.c. of oil in graduated cylinder, and pour into copper still, allowing the cylinder to drain into the still for several minutes. Attach lid and clamp, using a paper gasket slightly wet with oil around the flange of the still. Apply heat by means of the ring burner, which shall be placed just above the level of the oil in the still at the beginning of the test, and gradually lowered when most of the water has distilled over. Continue the distillation until the vapor temperature, indicated by the thermometer with the bulb opposite the offtake of the connecting tube, reaches 205°C. Collect distillate in separatory funnel. When the distillation is completed, and a clear separation of water and oil in the funnel has taken place, read the water by volume and draw off; and return any light oil distilled over with the water to the oil in the still. The dehydrated oil from the still shall be used for the distillation test.

III. MATTER INSOLUBLE IN BENZOL

4. **APPARATUS.** (a) *Extractor*.—The extractor may be of the form shown in Fig. 187, or any similar form in which the oil is subjected to direct washing, by the boiling vapors of the solvent.

(b) *Filtering Medium*.—The filtering medium may be either two thicknesses of S. & S. no. 575 hardened filter paper, 15 cm. in diameter, arranged in cup shape by folding symmetrically; or alundum thimbles.

¹ See Fig. 139, "Test for Water" Chap. XIV.

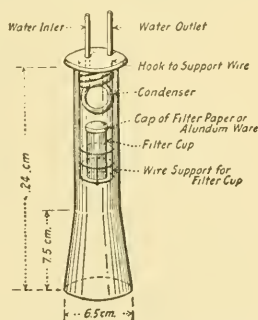


FIG. 187.—Extraction flask.

flat bottom, 30 by 80 RA 98. If filter papers are used, prior to using they shall be soaked in benzol to remove any grease, dried in a steam oven and kept in a desiccator until ready to be used. The filter-paper cup may be suspended in the extractor flask by a wire basket hung from two small hooks on the under surface of the metal cover of the flask. If the alundum thimble is used it may be supported by making two perforations in the top of the thimble, and suspending from the cover by german silver or platinum wires.

5. "INSOLUBLE IN BENZOL" TEST.—Weigh 10 g. of dry oil in 100-c.c.

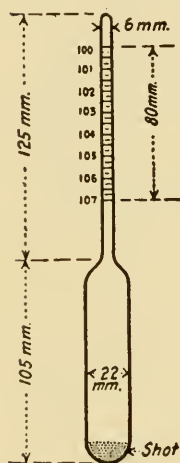


FIG. 188.—Hydrometer.

beaker. Add about 50 c.c. of pure benzol and transfer at once to the filter cup. The filter cup of thimble is previously weighed, and the paper cup shall always be kept in a weighing bottle until ready for use. Wash out the beaker with benzol, passing all washings through the filter cup, and place latter at once in the extraction apparatus. Extractor shall contain a suitable quantity of pure benzol. Sufficient heat to boil the solvent shall be provided by means of an electric heater or steam bath. Continue the extraction until the descending solvent is practically colorless, and remove the filter cup and dry in steam oven until all solvent is driven off; cool in desiccator and weigh. The balance used for this purpose should be accurate to 0.5 mg.

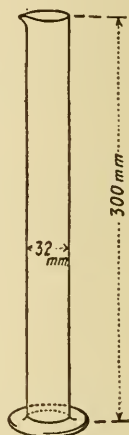


FIG. 189.—Cylinder.

IV. SPECIFIC GRAVITY

6. APPARATUS. (a) *Hydrometer*.—The hydrometer shall be of the form shown in Fig. 188. It shall have the following dimensions:

Length of stem.....	125 mm.; permissible variation, 12.5 mm.
Length of bulb.....	105 mm.; permissible variation, 10.5 mm.
Length of scale.....	80 mm.; permissible variation, 8.0 mm.
Diameter of stem.....	6 mm.; permissible variation, 0.5 mm.
Diameter of bulb.....	22 mm.; permissible variation, 2.0 mm.

A set of two hydrometers with ranges 1.00 to 1.08 and 1.07 to 1.15 will suffice.

(b) *Cylinder*.—The cylinder shall be of the form shown in Fig. 189. It shall have the following dimensions:

Length.....	300 mm.; permissible variation, 30 mm.
Diameter.....	32 mm.; permissible variation, 3 mm.

7. **SPECIFIC-GRAVITY TEST.**—The oil shall be brought to a temperature of 38°C. (100°F.), and the determination shall be made at that temperature unless the oil is not entirely liquid at 38°C. In case the oil requires to be brought to a higher temperature than 38°C. in order to render it completely fluid, it shall be tested at the lowest temperature at which it is completely fluid, and a correction made by adding 0.0008 to the observed specific gravity for each degree Centigrade above 38°C. at which the test is made. This correction factor does not apply with equal accuracy to all oils, but serious error due to its use will be avoided if the foregoing precaution is observed, with respect to avoiding unnecessarily high temperature. Before taking the specific gravity the oil in the cylinder should be stirred thoroughly with a glass rod, and this rod when withdrawn from the liquid should show no solid particles at the instant of withdrawal. Care should be taken that the hydrometer does not touch the sides or bottom of the cylinder when the reading is taken, and that the oil surface is free from froth and bubbles

V. DISTILLATION

8. **APPARATUS.** (a) *Retort.*—This shall be a tubulated glass retort of the form and approximate dimensions shown in Fig. 190, with a capacity

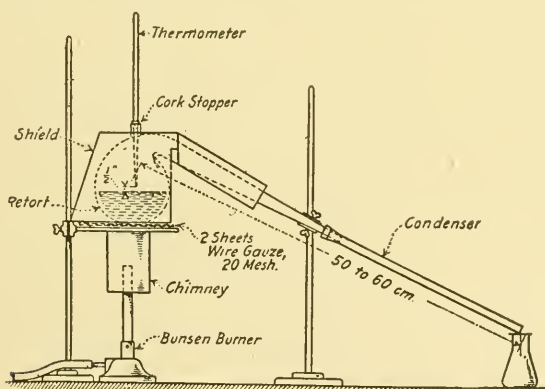


FIG. 190.—Assembled apparatus for distillation test.

of 250 to 290 c.c. The capacity shall be measured by placing the retort with the bottom of the bulb and the end of the offtake in the same horizontal plane, and pouring water into the bulb through the tubulature until it overflows the offtake. The amount remaining in the bulb shall be considered its capacity.

(b) *Condenser Tube.*—The condenser tube shall be a suitable form of tapered glass tubing of the following dimensions:

Diameter of small end.....	12.5 mm.; permissible variation 1.5 mm.
Diameter of large end.....	28.5 mm.; permissible variation 3.0 mm.
Length.....	360.0 mm.; permissible variation 4.0 mm.

(c) *Shield*.—An asbestos shield of the form and approximate dimensions shown in Fig. 190, shall be used to protect the retort from air currents and to prevent radiation. This may be covered with galvanized iron, as such an arrangement is more convenient and more permanent.

(d) *Receivers*.—Erlenmeyer flasks of 50 to 100-c.c. capacity are the most convenient form.

(e) *Thermometer*.—The thermometer shall conform to the following requirements (See "Distillation of Bituminous Materials Suitable for Road Treatment," Chap. XIV).

9. **ASSEMBLING APPARATUS FOR DISTILLATION TEST.**—The retort shall be supported on a tripod or rings over two sheets of 20-mesh gauze, 6 in. square, as shown in Fig. 190. It shall be connected to the condenser tube by a tight cork joint. The thermometer shall be inserted through a cork in the tubulature with the bottom of the bulb $\frac{1}{2}$ in. from the surface of the oil in the retort. The exact location of the thermometer bulb shall be determined by placing a vertical rule graduated in divisions not exceeding $\frac{1}{16}$ in. back of the retort when the latter is in position for the test, and sighting the level of the liquid and the point for the bottom of the thermometer bulb. The distance from the bulb of the thermometer to the outlet end of the condenser tube shall be not more than 24 nor less than 20 in. The burner should be protected from draughts by a suitable shield or chimney.

10. **DISTILLATION TEST.**—Exactly 100 g. of oil shall be weighed into the retort, the apparatus assembled and heat applied. The distillation shall be conducted at the rate of at least 1 drop and not more than 2 drops per second, and the distillate collected in weighed receivers. The condenser tube shall be warmed whenever necessary to prevent accumulation of solid distillates. Fractions shall be collected at the following points: 210, 235, 270, 315, and 355°C. The receivers shall be changed as the mercury passes the dividing temperature for each fraction. When the temperature reaches 355°, the flame shall be removed from the retort, and any oil which has condensed in the offtake shall be drained in the 355° fraction.

The residue shall remain in the retort with the cork and the thermometer in position until no vapors are visible; it shall then be poured directly into the brass collar used in the float test or into a tin box and covered and allowed to cool to air temperature. If the residue becomes so cool that it cannot be poured readily from the retort, it shall be re-heated by holding the bulb of the retort in hot water or steam, and not by the application of flame.

For weighing the receivers and fractions, a balance accurate to at least 0.05 g. shall be used.

During the progress of the distillation the thermometer shall remain in its original position. No correction shall be made for the emergent stem of the thermometer.

When any measurable amount of water is present in the distillate it shall be separated as nearly as possible and reported separately, all results being calculated on a basis of dry oil. When more than 2 per cent of water is present, water-free oil shall be obtained by separately distilling a larger quantity of oil, returning to the oil any oil carried over with the water, and using dried oil for the final distillation (see Sec. II, "Water Test").

SPECIFIC GRAVITY OF FRACTIONS

11. SPECIFIC GRAVITY OF FRACTIONS.—As specific gravity is an absolute physical determination, any recognized method which can be applied to the quantity and quality of material at hand to be tested must be considered satisfactory. The following methods are convenient and accurate means for the relatively small amounts of oil available in determining specific gravity of fractions to be tested.

12. LIQUID FRACTIONS. (a) *Apparatus*.—The Westphal balance may be used.

(b) *Test*.—If the fraction to be tested is liquid at a temperature not exceeding 60°C., the Westphal balance can be used with convenience and rapidity. A special type of Westphal balance is obtainable, designed for testing very small quantities. However, the ordinary type of Westphal balance can be adapted to testing small fractions by the use of special plummet. When using the ordinary balance with the special plummet, extra care is needed that the adjustment of the balance be accurately made. The plummet can readily be made in the laboratory from a piece of ordinary glass tubing 7 mm. outside diameter, sealed at the end, and melting into the glass where sealed a short platinum wire. After cooling place 9 to 10 g. of mercury in the tube, making a column 35 to 40 mm. high. Seal off the tube within 20 mm. of the top of the mercury column with blowpipe flame. The plummet shall have a length of about 55 to 60 mm. over all, and shall weigh between 10 and 12 g.

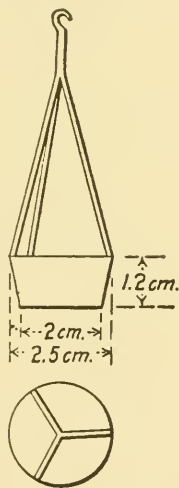


FIG. 191.—Platinum or nickel pan.

13. SOLID AND SEMI-SOLID FRACTIONS. (a) *Apparatus*.—A pan of the form shown in Fig. 191, having the following approximate dimensions, may be used:

Diameter of base.....	20 mm.
Diameter of top.....	25 mm.
Depth.....	12 mm.
Diameter of wire.....	1 mm.
Total weight.....	7 g.

The pan and wires are made of platinum or nickel.

(b) *Test*.—Solid or semi-solid fractions or oil which cannot be readily liquefied can be rapidly and accurately tested in this apparatus by the usual method of weighing in air and in water. The usual precautions of igniting the pan before use, and avoiding the enclosure of air or water in the sample, should be observed.

Note.—The method for liquid fractions is usually applicable to the fractions 235 to 315°C. and the method for solid and semi-solid fractions to the fraction 315 to 355°C.

14. FLOAT TEST OF RESIDUE.—See "Float Test," Chap. XIV.
VI. COKE RESIDUE

15. APPARATUS. *Bulb*.—The bulb shall be of hard glass, as shown in Fig. 192, and shall have the following approximate dimensions:

Diameter of bulb.....	15 mm.
Length of vertical neck.....	10 mm.
Length of horizontal neck.....	20 mm.
Diameter of orifice.....	1 mm.

16. COKE RESIDUE TEST.—Warm the bulb slightly to drive off all moisture, cool in a desiccator, and weigh. Again heat the bulb by placing it momentarily in an open bunsen flame and place the tubular underneath the surface of the oil to be tested and allow the bulb to cool until sufficient oil is sucked in to fill the bulb about two-thirds full.

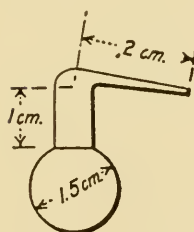


FIG. 192.—Coke bulb.

Any globules of oil sticking to the inside of the tubular should be drawn into the bulb by shaking or expelled by slightly heating it, and the outer surface should be carefully wiped off and the bulb re-weighed. This procedure will give about 1 g. of oil.

Cut a strip of thin asbestos paper about $\frac{1}{4}$ in. wide and about 1 in. long, place it around the neck of the bulb and catch the two free ends close up to the neck with a pair of crucible tongs. The oil should then be distilled off as in making ordinary oil distillation starting with a very low flame and conducting the distillation as fast as can be maintained without spurting.

When oil ceases to come over, the heat should be increased until the highest temperature of the bunsen flame is attained, the whole bulb being heated red hot until evolution of gas ceases, and any carbon sticking to the outside of the tubular is completely burned off. The bulb should then be cooled in a desiccator and weighed and the percentage of coke residue calculated to water-free oil.

347. Cost Data.—Typical data (1922) for the cost of a wood-block surface are:

	PER SQUARE YARD
Blocks (3½-in. depth).....	\$2.30
Handling to trucks.....	0.02
Hauling.....	0.20
Piling on street.....	0.02
Laying and rolling.....	0.10
Bituminous filler (plus 10 to 15 cts. if poured).....	0.18
Sand cushion (plus 10 cts. if cement is added).....	0.08
Contingencies and over-head.....	0.35
Profit.....	0.45
Total estimate.....	\$3.70

CHAPTER XXII

ASPHALT BLOCK

348. Composition of Asphalt Blocks.—The principles to be followed in the design of mixtures for asphalt blocks differ in no manner from those for bituminous sheet pavements (see Chap. XVI). The aggregate may be either sand or fine crushed stone. As with sheet mixtures success has been obtained with aggregates having various gradings according to sieve analyses. Any coarse sand commonly used for portland cement concrete and running approximately 35 to 45 per cent retained on the No. 20 sieve, can by the addition of from 10 to 25 per cent dust, be used in the manufacture of asphalt blocks. Just as with mixtures for sheet constructions, those for blocks range from hard to soft, varying with the amount and character of bituminous cement used and the manner in which it is combined with the mineral matter. Blocks that are too hard or friable will cobble in the same manner as stone or brick when laid with sanded joints. Those that are too soft will iron out so that the joints become invisible and the pavement wavy. It is not difficult to obtain a satisfactory mean, correctly placed between "too soft" and "too hard."

349. Block Specifications.—The standard block today has a 12 by 5-in. wearing face and a 3-in. depth. It is usually specified that in manufacturing the blocks they shall receive a compression in the molds of not less than 3 tons per square inch if compressed on the 5 by 12-in. face and a compression of not less than 4 tons per square inch if compressed on the 3 by 12-in. face of the block. Asphalt blocks having depths of 2 and $2\frac{1}{2}$ in. are also on the market. Generally a variation of $\frac{1}{4}$ in. from the specified size is permitted, though some cities, while allowing $\frac{1}{4}$ in. in length, permit not to exceed $\frac{1}{8}$ in. in width or depth.

350. Density of the Blocks.—It has been often stated that since blocks are formed under pressure in molds they have greater density than asphalt mixtures in sheet pavements. This inference is misleading because the density of asphalt mixtures whether in block or sheet pavements depends primarily upon the mineral matter and its grading; and it has been found that

specimens having identical compositions, have approximately equal densities, whether taken from block roadways or sheet.

351. Asphalt Specifications.—Blown petroleumums or combinations of native asphalt and flux of low ductilities are usually used for asphalt blocks. The American Society for Testing Materials Tentative Specifications for asphalt cement, serial designations, D133–22T and D134–22T are:

The asphalt cement shall be homogeneous and free from water. It shall conform to the following requirements:

Penetration at 25°C. (77°F.), 100 g., 5 sec.....	} See Note ¹
Ductility at 25°C. (77°F.).....	

¹ *Note.*—D133–22T specifying penetrations of from 10 to 15 points calls for ductilities of from 5 to 15 cm; and D134–22T, specifies penetrations of 15 to 25 points corresponding to ductilities of 5 to 20 cm.

Flash point (open-cup) not less than 200°C. (392°F.)

Loss on heating at 163°C. (325°F., 50 g., 5 hr.) not more than 1 per cent.

Penetration at 25°C. (77°F.), 100 g., 5 sec., of residue after heating at 163°C. (325°F.), as compared with penetration of asphalt cement before heating, not less than 50 per cent.

Proportion of bitumen soluble in carbon tetrachloride not less than 99 per cent.

The properties enumerated in these American Society for Testing Materials specifications are to be determined in accordance with the methods of test set forth in Chap. XIV.

352. Information as to Cost.—An asphalt block surface, requiring more labor for manufacture and construction, costs more than a bituminous sheet surface. This is true even when the streets to be paved are in the same locality as the asphalt block plant. When blocks are shipped a long distance, high transportation charges lead to an excessively costly pavement. However, in many cases, there not being sufficient paving required to justify the installation of a plant for sheet construction, the payment of a large freight bill for blocks may be justified. Blocks can be kept on hand for repairs which can be made easily without special apparatus. Those taken up on account of sub-surface construction can in large part be used in repairing the cut in the pavement. In general the life of an asphalt block surface may be assumed to be about equal to that of a sheet surface, but during the late years of its life it is rough for travel. With blocks, as smooth repairs cannot be made as with plastic mixtures which in the laying can be feathered out to do away with even slight inequalities in the pavement.

CHAPTER XXIII

TREES FOR CITY PLANTING

353. The Tree System in General.—A satisfactory tree system can be had only when an organization and sufficient funds are available for methodically carrying out a definite project providing not only for planting the trees but also for systematic trimming, spraying and other maintenance. To follow the very usual custom of permitting property owners individually to plant their own trees results in lack of uniformity in the variety of trees, irregularity in spacing, and the selection of trees of inferior quality. Wanting intelligent maintenance, the trees fail from the standpoint of both beauty and shade, low hanging limbs interfere with traffic and insect pests annoy adjacent property owners.

The proper location for trees is at the curb, though this is disputed by many. It may be cheaper to put sidewalks next to the curbs and the trees at the backs of the walks, and undoubtedly trees so located interfere with street lighting less than when located at the curbs, but this latter position gives a balanced effect to the street that outweighs the disadvantages. Moreover, terraces back of the sidewalks are usually raised several feet and this height, varying from block to block makes it impossible to get uniform plantings. For ordinary streets only curb trees (but one line of trees on each side of the street) should be used; when a second row is planted between sidewalks and buildings, even on streets as wide as 120 ft. between building lines, the trees are crowded and more shade than necessary is furnished. Often for second-row trees rapid growing ones have been used much to the detriment of hard wood trees at the curb on account of the latter being over-shadowed. Under such conditions the curb trees grow mostly on the roadway side and lean over the gutter to such an extent that vehicles brush against the tree trunks and suffer damage.

A common mistake is the planting of trees with intervals that are much too short. A spacing of 20 ft. is often adopted, whereas

35 ft. should be the minimum, and this minimum to be adopted only in the case of the smaller varieties of trees. In each block the trees should be spaced so as to give a balanced appearance to the street. However, on one side they need not be planted directly opposite those on the other side of the street, nor do the intervals between trees need to be equal. Lamps, fire hydrants and other public appurtenances should be given consideration. Trees as far as practicable, should be planted on the extensions of property lines between lots, then they will not interfere with future driveways to garages, nor with entrances to homes or other buildings. Norway maples may be spaced from 35 to 45 ft., oaks from 50 to 65 ft., and elms from 55 to 70 ft. The planting of rapid growing trees such as silver maples or Carolina poplars between the hard wood slow growing species has often been advocated in order to give early shade, the intention being to remove these intermediate trees after the hard wood ones have grown to a fair size. This practice is not to be recommended because the quick growing trees over-shadow those of slower growth and retard them, leading to the development of poor misshapen specimens.

354. The Selection of Trees.—Four desirable qualities for trees for street planting are; symmetry, cleanliness, immunity from insects, and abundance of shade. It is well to use trees that are easily propagated, and they should be able to endure transplanting. In addition they should be hardy and capable of withstanding the unfavorable conditions of city life, such as poor soil, heat, drought, smoke and dust. In choosing trees, those native to a locality should be given first choice since trees adapted to local soil and climatic conditions have much more chance of growing under city conditions than do imported varieties. Of the native trees available, for important locations at least, selection should be confined to those trees which are known to have given good service under city conditions. However, a number of streets favorable for the purpose should be given over to experimental planting in order that the city may fully understand and appreciate the possibilities of various kinds of trees. Most trees are easily propagated from seed which is not difficult to procure, and it will be found that for any city of fair size a municipal nursery will not only prove to be economical, but the results obtained with the trees will be much better than if they were purchased of planting size from distant nurseries. While

in the municipal nursery continuous attention as to pruning and training can be given, and with ordinary care losses when the trees are transplanted to the streets should be practically negligible.

355. Three Excellent Trees.—The main structure of a city's tree system may be built upon but a few well-chosen varieties of trees. A choice of only three is sufficient, as it is doubtful that anything is gained by a greater variety. On important streets it is a good plan to continue one kind of tree from beginning to end across the city. The red oak, Fig. 193, ranks with the foremost of



FIG. 193.—Red oaks.

shade trees. It has all the good qualities of the other oaks and practically no faults. It is a large, oval, open-headed tree of relatively rapid growth, with large green leaves. It is such a handsome tree, requires such little care, and is generally so very satisfactory that it is a pity that it has not been more universally used for street planting. It is believed that but one tree equals the red oak for street purposes and that is the American elm, Fig. 194, though this tree being tall and spreading differs radically from the red oak, and is graceful rather than majestic as is the latter. A third very satisfactory tree is the Norway maple,

Fig. 195, which on account of its good shape, its attractive green foliage during spring and summer, and its color in the autumn, has found much favor for street planting.



FIG. 194.—Spraying elms with arsenate of lead.



FIG. 195.—Norway maples.

356. Undesirable Trees.—Objectionable features that should be given consideration in choosing trees may best be brought out by discussing two most undesirable varieties. The silver maple has probably been more used for street planting throughout the United States than any other tree and yet it is one of the least

desirable and should not be used where any other tree will grow. It is a surface rooter; its wood is brittle and easily broken by ordinary wind storms, and the whole tree is subject to early decay. Its autumn foliage is unsightly. Of the 100,000 trees in the city of Washington more than one-fifth are mature silver maples, trees that in another decade will have entirely disappeared from the streets. If the red oak, the American elm or the Norway maple had been used instead, not only would the past generation have received superior pleasure but the benefits derived would be continued for generations to come. Another undesirable tree is the Carolina poplar. It also is a surface rooter. It begins to lose its leaves early in summer and is completely defoliated early in the autumn. The wood is easily broken and the trees grow so rapidly with long branches and heavy tops that practically every wind storm causes an unreasonable amount of damage. The Carolina poplar is a vigorous tree and grows under most difficult conditions, but it should not be planted if any other tree can be made to meet requirements.

357. Care and Abuse of Trees.—Trees on city streets require a great deal of special care and attention. First of all to take the place of top soil which is usually removed when streets are placed on grade, and to insure a feeding ground of the best quality possible, a hole about 6 by 3 ft., and 3 ft. deep should be dug and filled with rich soil. Watertight pavements and buildings completely surround practically many street trees with the exception of small areas adjacent to their trunks. It is remarkable that the trees live at all, and yet with good care they apparently flourish as well as do those growing under natural conditions. For the first year after placing the tree on the street, systematic cultivation should be carried out, the earth about the tree being kept loosened and in very dry periods it should be watered.

To protect the tree and hold it upright while young a tree box is necessary. A wooden one is satisfactory, and instead of having four sides as is usual, but three should be used, thus saving one-fourth the cost. Boxes for mature trees as protection against draft animals are not needed in this day of motorized transportation. While the tree is young it should be trained into a good shape by skillful pruning. After maturity methodical trimming is required for the elimination of dead wood and such low hanging branches as would, particularly after rain storms, hang so low as to interfere with pedestrians on the sidewalks or vehicles on the

roadways. Careful and persistent efforts are necessary at all times if control of the many shade tree pests prevalent in cities is to be had. Disregard of this duty results in complete defoliation and after a few seasons in death, because trees hampered by unfavorable city conditions do not have the resistance to and immunity from insect enemies that forest trees have. If a city is equipped with adequate spraying and other outfits insects and ordinary diseases can readily be controlled.



FIG. 196.—Generally it is bad practice to head trees back as illustrated in this picture. Sycamores withstand such cutting better than any other trees and fair results can be obtained as evidenced by the next photograph; however, these illustrations show mostly that sycamores, especially when planted at short intervals are a poor choice for streets of ordinary width.

Generally the practice of what is known as “heading back” illustrated in Fig. 196, is to be condemned, the one possible exception being in the case of the sycamore. The photograph, Fig. 197, shows sycamores the second season after having been severely headed back. When work of this nature is carried out by competent persons and for well-founded reasons satisfactory results may be had. Often though, man on one excuse or another abuses and wantonly destroys much of the beauty of a city’s tree system. In making house connections for gas, water and other utilities laborers cut through the main roots of trees instead of digging carefully around them. Linemen slash into the tops of trees as



FIG. 197.—Sycamores the second season after severe heading back. The branches of the trees prior to cutting, met over the center of the roadway and on the building sides were a nuisance to the householders.



FIG. 198.—The mutilation by linemen of handsome pin oaks. Wires should be collected into armored cables or be placed underground.

shown by Fig. 198, which illustrates the mutilation of what were handsome pin oaks. When trees interfere with over-head wires the latter should be grouped into armored cables or special "tree wire" should be used which can be strung through the branches without injury to either the trees or the wires; or else the wires should be placed underground. There are also many other abuses, as for instance trees in front of soda fountains are killed by salt water drained from ice-cream cans, and those in front of garages by grease deposited on the ground about them.

358. U. S. Department of Agriculture Information.—The U. S. Department of Agriculture publishes for free distribution a great deal of accurate and valuable information about trees, the following being of particular importance:

Farmers' *Bulletin* 1208. "Trees for Town and City Streets."

Qualities necessary for street trees.

Division of the United States into 13 regions with lists showing trees adapted to each region.

Description of different trees.

Farmers' *Bulletin* 1209. "Planting and Care of Street Trees."

Importance of shade trees.

Public control of shade trees.

Planning for trees on city streets.

Spacing trees.

Conditions for tree growth.

Trees suitable for city streets.

Culture of street trees.

Care of mature trees.

Farmers' *Bulletin* 1123. "Growing and Planting Hardwood Seedlings."

Seed collection, extraction and storage.

Growing the seedlings.

Transplanting.

Farmers' *Bulletin* 181. "Pruning."

Purpose of pruning.

Pruning implements.

Pruning for specific purposes.

Application of pruning to specific plants.

Farmers' *Bulletin* 1178. "Tree Surgery."

The danger of neglected wounds.

The details of tree surgery.

Guying.

Farmers' *Bulletin* 1169. "Insects Injurious to Deciduous Shade Trees and their Control."

The principles of shade-tree insect control.

The various methods used for the control of insects and disease.

Spraying outfits and accessories.

Insects arranged according to the manner of attack.

Farmers' Bulletin 701. "The Bagworm, an Injurious Shade-tree Insect."

Farmers' Bulletin 708. "The Leopard Moth, a Dangerous Imported Insect Enemy of Shade Trees."

Farmers' Bulletin 845. "The Gipsy Moth and the Brown-tail Moth and their Control."

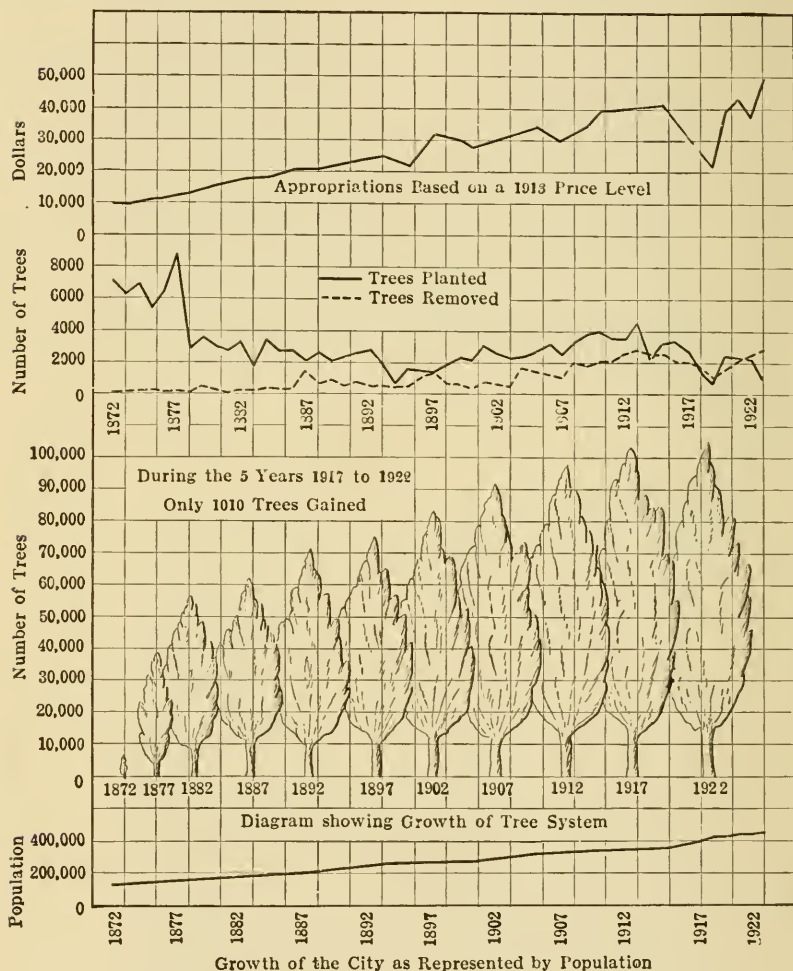


FIG. 199.—Data pertaining to the tree system of the District of Columbia.

359. Cost Data.—In Fig. 199, are set forth data pertaining to the trees of the city of Washington, picturing the growth of the tree system from its inception in 1872 up to date. Unfortunately, among the 105,889 street trees in the city there are many poor

specimens (22,636 are silver maples), all of which will probably be removed during the next 10 years. While few or no undesirables have been planted since 1900, the early use of such trees has placed an undue burden upon the city in that they require a great deal of care and then have to be removed and replaced after an unreasonably short life. With a tree system that has been brought to a total of 100,000 trees after well-organized planting of well-chosen varieties for 50 years, no more than 1,000 replacements should be required during the fiftieth year, with but slight increases thereafter. Instead, in Washington, on account of the early choice of undesirable varieties it has been common practice to remove more than 2,000 trees for some years past, and there undoubtedly will be removed an average of 3,500 trees each year during the next 10 years.

Assuming that a city has a system of 100,000 trees and that the removal of 1,000 and the planting of 4,000 (to cover replacements and to keep pace with the growth of the city), would be necessary in the fiftieth year, an appropriation of \$50,000, would be required which including allowances for depreciation and maintenance of equipment would be expended about as follows:

Administration and overhead, locating trees on plats, transportation for superintendent, etc.	\$ 7,000
Planting seed and raising 4,000 trees to age fit for street @ 50 cts. . .	2,000
Digging 4,000 tree holes and filling with rich soil @ \$3.75.	14,000
Lifting 4,000 trees and planting on street @ \$1.10.	4,400
4,000 tree boxes @ 90 cts.	3,600
Placing 4,000 tree boxes @ 25 cts.	1,000
Removal of 1,000 trees (varies from \$1 to \$20 each).	5,000
Trimming 20,000 trees @ 20 cts.	4,000
Spraying etc., 60,000 trees @ 10 cts.	6,000
Cultivating, general care of tree spaces and tree boxes and miscellaneous work.	3,000
	\$50,000

INDEX

References are to pages

A

- Abrasion tests, 371
- Aggregates (*see* Bituminous aggregates, etc.).
 - bulking effect of bituminous cement, 330
 - of moisture, 186
 - cost, 170
 - fineness modulus, 182
 - large, 201, 203
 - specifications, 161
 - surface area, 184
 - voids, 185, 195, 323
- Alleys, cross sections of, 131
 - necessity of, 50
 - pavements for, 90
 - records for, 14
- Arcaded buildings, 41
- Asphalt (*see* Bituminous).
 - block (*see* Block pavements).
 - classes of, 267
 - rock, 334

B

- Barrow, dimensions, 188, 198, 201
- Bids, instructions for bidders, 27
 - proposal form, 26
 - unbalanced, 23
- Bituminous aggregates, 319, 331
 - sieve analysis, 320
 - voidage, 323
- block (*see* Block pavements).
- construction, binder course, 320, 322
 - bitumen requirements, 321, 330
 - cold patching, 310
 - cost data, 348
 - cracks, 74, 322
 - dust, loss of, 344
 - palliatives, 308

- Bituminous construction, dusting
 - the surface, 348
- flexible base, 74, 330
- hot mix method, 313
- mat construction, 309
- mixing, 342
 - costs, 348
- patching, 348, 351
- penetration method, 313
- plant, 339
- repair of, 348, 351
- rolling, 346
- salvaged mixtures, 352
- service from, 69
- smoothing iron, 347
- spreading the mixture, 345
- surface finishing, 346
 - treatment, 64
- surfacing old roadways, 75
 - residential local streets, 68
 - stone block roadways, 78
- tamping, 347
- transportation, 344
- design of mixtures, 319
- aggregates, 320, 331
- binder course, 320
- bitumen requirements, 321, 330
- bituminous cements, 333
- filler, 328
- pat tests, 335
- penetration, 272, 317, 330
- sieve analyses, 320
- specific gravity, 303, 323, 332
- standards for reference, 328
- sulphurized asphalt, 334
- weight per square yard, 323, 332
- distributor, 308
- filler for block pavements, 362
- maintenance, 307, 348
 - salvaged materials, 352
- mastic filler, 366

- Bituminous materials, classes of, 267,
307
cold patching, 310
definitions, 268
dust palliatives, 308
mat construction, 309
native asphalt and other prod-
ucts, 317
penetration and mixed work,
313
rock asphalt, 334
sampling, 270
sulphurized asphalt, 334
mixtures, 319
action of water, 337
extraction of bitumen, 298
salvaged materials, 352
weight per square yard, 323, 332
patching, 348
plant, 339
specifications, 307, 319, 362
tests, apparatus for block test, 326
benzol solubility, 395
block test, 325
carbon disulfide, soluble bitu-
men, 294
tetrachloride, soluble bitu-
men, 301
cube in water softening point,
283
distillation of wood preserva-
tive, 397
test, 288
ductility, 302
flash test, 291
float test, 274
hydraulic press, 325
loss on heating, 286
melting point, 281, 283
pat test, 335
penetration test, 272
ring and ball softening point,
280
sampling, 270
softening point, 281, 283
soluble bitumen, 294, 298, 301,
395
specific gravity, 303
water in wood preservatives, 395
test, 279
- Block pavements, abrasion tests,
371
asphalt block, asphalt specifica-
tions, 403
composition of, 402
cost data, 403
density of, 402
specifications for, 402
basalt, 375
bedding the blocks, 361
bituminous surfacing, 78, 350
brick, character of, 378
cost data, 389
rattler tests, 379
specifications, 379
varieties of, 378
cement-sand cushion, 358
cushion layers, 357
durax, 376
expansion joints, 367
filler specifications, 362
filling the joints, 362, 365
granite block, 369
cost data, 374
durax, 376
Manhattan specifications, 370
recut, 374
tests, 371
headers, 367
laying the courses, 359
Medina sand stone, 375
paint coat bed, 358
parging along rails, 367
Portland cement grout filler,
366
rattler tests, 379
rolling the blocks, 362
sand cushion, 358
sandstone, 375
sanded joints, 367
stone block, 369, 375
recut, 374
tests, 371
tests, value of, 374
toughness tests, 371
wood block, cost data, 401
preservative, 392
specifications, 390
test for preservative, 394
treatment, 391

Bonds, serial, 58
 sinking fund, 57
 Brick (*see* Block pavements).

C

Catch basins, 104
 Cement (*see* Concrete)
 bag, 140, 187
 barrel, 140, 187
 bulk, 233
 careful testing necessary, 158
 chemical limits, 141
 properties, 144
 comparative tests, 159
 consistency, 149
 cost, 159
 definition, 140
 fineness, 147
 insoluble residue, 142
 inspection, 140
 loss on ignition, 141
 magnesia, 143
 marking, 140
 mortars, 149
 packages, 140
 pastes, 149
 ratio to space occupied, 192
 rejection, 141
 sampling, 141
 soundness, 151
 specific gravity, 146
 specifications for, 139
 storage, 140
 of test pieces, 157
 strength, 155
 sulfuric anhydride, 142
 tension test, 156
 time of setting, 154
 City planning, block divisions, 49
 highway plan, 11, 33
 zoning, 33
 Colorimetric test, 164
 Compression tests (*see* Concrete tests).
 Concrete (*see* Cement).
 aggregates, coarse, 167
 colorimetric test, 164
 cost, 169
 denseness, 193
 Concrete, aggregates, fine, 166
 aggregates, large, 201, 203
 measuring, 187
 organic impurities, 164
 quality, 170
 sampling, 162
 sieves, 162
 silt, clay and dust, 163
 sizes, 166
 specifications, 161, 168
 tables of quantities, 206
 tests, 161
 unit weight, 165
 voids, 185, 195
 cement, ratio to space occupied, 192
 compression tests (*see* Concrete tests).
 consistency, comparison of tests, 176
 flow test, 174
 for hauling, 235
 necessity of tests, 175
 slump test, 174
 construction (*see* Concrete mixers, etc.).
 base construction, 247
 required by traffic, 70
 thickness, 74
 bridge for workmen, 249
 cold weather, 260
 contraction, 66, 91
 core specimens, 246
 cost data, 261, 262
 cracks, 66, 263
 curing, 259
 expansion, 66, 91
 finish machines, 250
 hose for surface finish, 251
 joints, 66, 252, 263
 maintenance, 261
 one course roadway, 248
 reinforcement, 66
 repair of, 67, 261
 repairs of base, 73
 residential local streets, 64
 rigidity and flexibility, 71, 74
 rolling the surface, 251
 screeding, 249
 sidewalk, subgrade, 247

- Concrete specifications, 244
 subgrade, 244, 247
 surface finish, 250
 thickness of, 65
 curb, 258
 curing, 177, 259
 necessity of, 178
 design of mixtures, aggregate
 measurement, 187
 denseness, 193
 mixture, cement space ratio,
 192
 economical, 197, 236
 fineness modulus, 182
 measuring ingredients, 187
 proportioning tables, 204
 surface area, 184
 tables of quantities, 206
 voids, 185
 water-cement ratio, 188, 235
 exposed aggregate, 257
 mixers, boom and bucket, 225
 capacities, 228
 Class E mixers, 223
 Class S mixers, 220
 costs of mixers, 219
 data as to sizes, 220
 lost time, 230
 output, 229
 power, 224
 ratings, 227
 traction, 224
 types of mixers, 219
 mixing, 225
 central plant, 233, 239
 proportioning, 232
 for tests, 173
 hand mixing, 226
 machine mixing, 225
 retempering, 226
 roadside, 231
 speed of drum, 227
 time, 226
 water for mixing, 188, 226, 235
 plant, central mixing, 233
 cost, 18
 industrial railway, 242
 proportioning, 232
 transportation, 231, 234, 236, 241
 proportioning, central plant, 232
 Concrete proportioning, mixtures,
 204
 roadside, 231
 tables, 206
 quality of, 181
 roadways (*see* Concrete, construc-
 tion).
 sidewalks (*see* Concrete, con-
 struction).
 specifications, 244
 strength, 171, 181
 curves, 195, 198
 estimating chart, 202
 tests, age at test, 178
 capping cylinders, 177
 cement test, 172
 coarse aggregate, 172
 cone test, 174
 consistency, 174
 curing test pieces, 177
 density and yield, 179
 fine aggregate, 172
 flow test, 174
 forms for test pieces, 177
 load, 179
 mixed aggregate, 172
 mixing concrete, 173
 molding test pieces, 177
 record, 179
 sampling for test, 172
 sequence of test, 179
 size of test pieces, 173
 slump test, 174
 weight of concrete, 179
 trucks, 234, 236
 voids, 185, 235
 water for mortars, 151
 ratio to cement, 188
 Consistency (*see* Cement, concrete).
 Construction, 6 (*see* Bituminous
 construction, etc.).
 Contours, roadway, 121
 street intersections, 123, 129
 Contracts, award and execution of, 27
 classes of, 21
 definition of terms, 27
 Fall and Winter letting of, 22
 guarantee and maintenance, 24
 inspection under, 24
 notice to contractors of, 26

Contracts, proposal form for, 26
 relations of parties to, 21
 specifications for, 25
 unbalanced bids, 23

Cost keeping, 16

Curb, circular, 102
 concrete, 258
 design of, 94
 grade determination, 124
 granite, 376
 height and slope, 112
 materials for, 94
 radius for, 102
 stone, 376
 tests of materials, 376

Curves (*see* Roadways).

D

Distillation tests, 288, 397
 Drainage, catch basins, 104
 curb inlets, 105
 ditches, 104
 gutter inlets, 102
 minimum street grades, 102
 sub-grade, 103
 tile drains, 104
 Drills, bituminous maintenance, 352
 concrete, maintenance, 261
 for core specimens, 246
 Durax (*see* Block pavements).

F

Fineness modulus, 182

G

Grades, adverse, 110
 broken, 109
 cuts and fills, 109
 maximum, 108
 minimum, 102
 relationship to slipperiness, 84
 vertical curves, 110
 Grading, checking the subgrade, 245
 concrete construction, 244
 cost to property, 109
 Granite block (*see* Block pavements).
 Gravel (*see* Aggregates).
 Gutters, design of, 113
 materials for, 95

H

Highways (*see* Roadways).
 plans for, 11, 16, 33
 traffic, 40
 capacity, 43
 development, 44

L

Local streets, 46

M

Macadam, bituminous patching, 349
 treatment, 64
 rigidity and flexibility, 71, 74
 uneconomical use of, 45
 Maintenance (*see* Bituminous construction, etc.).
 air drills, 261, 352
 cost of, 60
 guaranteed in contract, 24
 organization for, 6
 program for, 56
 utility cuts, 8
 Manholes, 107
 Maps (*see* Records).
 Mortar, influence in concrete, 185,
 203
 strength, 168
 Motor vehicles for concrete, 234,
 241
 cost to roadways, 62
 loading of, 41
 number in United States, 63
 transportation cost, 241, 344
 weight of, 82
 widths of, 35, 82

O

Organization, Bureau of Highways,
 3, 5
 construction and maintenance, 6
 division of cuts, 8
 forms of, 4
 office engineer, 7

P

- Parabola, roadway crown, 116
 - transition curves, 135
 - vertical curve, 110
- Parkings, (*see* Streets).
- Pavements (*see* Bituminous, block, sidewalks, etc.).
 - abutting property owners, 61
 - adjacent to car tracks, 86
 - alley, 90
 - annual cost of, 59
 - assessments for, 61
 - choice of wearing surface, 80
 - cleanliness, 85
 - core drill specimens, 246
 - economy in service, 52
 - financing, 57
 - grades on, 84
 - impact and rigidity, 74
 - maintenance, 6
 - manholes and valve boxes, 107
 - noise of traffic, 85
 - program for, 52
 - selection of, 52
 - slipperiness, 84
 - traffic resistance, 83
- Plans (*see* City planning, records, etc.).
- Plant (*see* Bituminous plant).
 - (*see* Concrete plant).
 - cost, 18

R

- Railways (*see* Rapid transit, tracks, etc.).
 - industrial, 242
- Rattler tests, 379
- Records, alley sheets, 14
 - cards for, 19
 - cost keeping, 16
 - highway maps, 16
 - plan, 11
 - measurement sheets, 15
 - necessity of, 11
 - progress maps, 16
 - street grade sheets, 12
 - work sheets, 13
 - topographic map, 11
 - traffic, 19
- Roadways (*see* Bituminous construction, etc.).
 - contour diagrams, 121
 - crown across car tracks, 120
 - formula, 114
 - symmetrical distribution, 115
 - unsymmetrical distribution, 117
 - curves, extra width, 135
 - super-elevation of, 132
 - transition, 135
 - models for, 130

S

- Sand (*see* Aggregates).
- Screeds, bituminous construction,
 - 76, 79, 345
 - concrete roadway, 249
 - sidewalks, 253
- Sidewalks, choice of pavements, 90
 - cost data, 262
 - exposed aggregate, 257
 - floating the drier, 254
 - joints, 252, 254
 - one course vs. two course, 90
 - construction, 255
 - screeding, 253
 - subgrade, cost, 257
 - surface finish, 255
 - traffic highways, 41
 - transverse grades, 112
 - two course construction, 252
- Sieves, 162
- Specific gravity aggregates, 193,
 - 203, 323
 - bituminous materials, 303, 396
 - mixtures, 327, 332
 - cement, 146
- Specific viscosity, 277
- Specifications, cement, 139
 - composition of, 25
 - construction details, 29
 - cover page, 26
 - definition of terms, 27
 - general stipulations, 28
 - special provisions and details, 28
 - standard, 25
- Stone block (*see* Block pavements).
- Streets (*see* Highways, etc.).
 - block divisions, 49

Streets, business, 40, 47
 classes of, 35
 cross sections, 112
 grades, maximum, 108
 minimum, 102
 sheets for, 12
 industrial, 47
 intersections, acute, 98
 circular, 100
 contour diagrams, 123
 curb for, 102
 grade determination, 122
 models for, 130
 multiple, 100
 plans for, 97
 local, 46
 parkings, 34
 heights, 112
 widths, 41
 rapid transit, 35
 development, 38
 sidewalks and parkings, 41
 traffic highways, 40
 width of, 34
 work sheets for, 13
 Surface area of aggregates, 184

T

Tars (*see* Bituminous).
 classes of, 307
 Tests (*see* Bituminous, block, cement, concrete).
 Thermometer, standard, 289, 292
 Toughness tests, 371
 Tracks, parging along rails, 367
 pavements adjacent to, 86
 roadway cross sections, 120
 Traffic, cost of, 62
 Impact, 74
 loads, 82
 noise of, 85
 records, 19
 resistance to, 83

Traffic highways, 40
 capacity, 43
 development of, 44
 sidewalks and parkings, 41
 Transportation, cost of, 62, 241, 344
 Trees, abuse of, 408
 boxes for, 408
 care of, 408, 411
 Carolina poplar, 408
 cost data, 412
 Department of Agriculture information, 411
 elms, 407
 insects, 407, 409, 411
 location of, 404
 municipal nursery, 405
 Norway maples, 407
 pin oaks, 410
 planting, 411
 pruning, 411
 red oaks, 406
 selection of, 405, 411
 silver maples, 408
 spacing of, 404
 spraying for insects, 407
 superintendent of, 6
 surgery, 411
 sycamores, 410
 the tree system, 404
 three excellent species, 406
 undesirable species, 407
 Washington, 412

V

Valve boxes, 107
 Vehicles (*see* Motor vehicles).

W

Wood block (*see* Block pavements).

Z

Zoning, influence of, 33

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Besson, Frank Schaffer, 1886-
 City pavements, by F. S. Besson. 1st
 ed. New York, McGraw-Hill, 1923.
 xi, 421 p. illus. 24 cm.

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